Studies on the environmental and genetic parameters for lamb survival, growth and wool traits of the Elsenburg Dormer and SA Mutton Merino flocks

By

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Declaration

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Summary

Environmental and genetic parameters and trends of the Elsenburg South African Mutton Merino (SAMM) and Dormer resource flocks were estimated. The breeds were also compared for lamb survival, growth, wool, carcass and meat quality traits. Early growth and lamb survival data over a 64-year period (1955 - 2019) and yearling weight and wool data over a 36-year period (1983 - 2019) were used in the study for SAMM sheep. Single-trait heritability estimates of SAMM lambs amounted to 0.07 for birth weight (BW), 0.03 for weaning weight (WW), 0.02 for lamb survival (LS), 0.24 for yearling weight (YW), 0.58 for clean yield (CY), 0.37 for clean fleece weight (CFW), 0.34 for staple length (SL), 0.55 for coefficient of variation of fibre diameter (CVFD) and 0.68 for fibre diameter (FD). Maternal heritability estimates were 0.15 for BW, 0.06 for WW and 0.01 for LS. Multi-trait heritability estimates compared well with the single-trait estimates. Genetic correlations among weight traits ranged from 0.04 for BW and YW to 0.81 for WW and YW. Low to moderate correlations among yearling traits accorded with previous literature for wool breeds. Genetic trends showed favourable but extremely slow genetic responses. Data from 1943 to 2019 were used to investigate genetic and environmental parameters and trends for early growth traits and LS in the Dormer flock. Yearling live weight- and wool traits were recorded for a shorter period from 2008 to 2018. Direct single-trait heritability estimates were 0.15 for BW, 0.06 for WW, 0.02 for LS, 0.19 for YW, 0.63 for CY, 0.56 for CFW, 0.59 for SL, 0.59 for SS, 0.60 for CVFD and 0.80 for FD. Maternal genetic effects amounted to 0.21 for BW, 0.08 for WW and 0.06 for YW. Genetic correlations among live weight traits ranged from low (-0.11) between BW and YW to very high (0.93) for WW and YW. Genetic correlations among wool traits were mostly low. Genetic trends for all weight traits suggested significant positive trends with time. Expressed relative to the overall phenotypic mean, these trends amounted to 0.12% for BW, 0.16% for WW and 0.45% for YW. Selection from 2013 for direct-, maternal- and a combination of direct and maternal breeding values up to 2019 resulted in genetic trends amounting to 0.07% for BW, 0.79% for WW and 1.01% for YW in the line selected on direct breeding values for WW. Corresponding genetic trends amounted to respectively -0.51%, 0.17% and 0.27% in the line selected on maternal breeding values for WW and respectively -0.20%, 0.41% and 0.58% in the line selected for a combination of direct and maternal breeding values. Maternal genetic trends were markedly smaller in magnitude even in those lines were selection was based on maternal breeding values. Results indicated that SAMM lambs were heavier at birth compared to their Dormer contemporaries (4.19 vs. 4.13 kg). Dormers were heavier than SAMMs at weaning (27.3 vs. 25.0 kg) and also when weighed as yearlings (49.7 vs. 47.8 kg). Dormer lambs had a higher survival rate than SAMM lambs at 0.89 and 0.81, respectively. Clean fleece weight was the only wool trait not affected by breed. Dormer yearlings had a higher CY and SL than SAMM yearlings. In contrast, SAMM yearlings had a lower CVFD and finer wool than their Dormer contemporaries (respectively 22.4 vs. 28.6

µm). The two breeds did not differ for slaughter weight, carcass weight or dressing percentage. Dormers had a thicker subcutaneous fat cover at the rump than SAMM contemporaries (5.00 vs 4.18 mm). It was concluded that all traits considered were variable and heritable, although selection responses to traits such as lamb survival and weaning weight in SAMMs may be slow. Breed differences for economically important traits were consistent with the roles of the two breeds, with the Dormer as a coarse-woolled terminal sire breed and the SAMM as a dual-purpose breed.

Opsomming

Omgewings- en genetiese parameters en -tendense van die Elsenburg Suid-Afrikaanse Vleismerino (SAVM)- en Dormerhulpbronkuddes is geëvalueer. Die rasse is ook vir lamoorlewing, sowel as groei-, wol-, karkas- en vleiseienskappe vergelyk. Data vir vroeë groei en lamoorlewing van SAVM's oor 'n 64-jaar periode (1955 - 2019) is gebruik, terwyl jaaroudgewig en woleienskappe oor 'n periode van 36 jaar (1983 - 2019) ontleed is. Beramings van enkel-eienskap oorerflikheid was 0.07 vir geboortegewig, 0.03 vir speengewig, 0.02 vir lamoorlewing, 0.24 vir jaaroudgewig, 0.58 vir skoonopbrengs, 0.37 vir skoonvaggewig, 0.34 vir stapellengte, 0.55 vir koëffisiënt van variasie (KV) van veseldikte en 0.68 vir veseldikte. Maternale oorerflikheidsberamings was 0.15 vir geboortegewig, 0.06 vir speengewig en 0.01 vir lamoorlewing. Beramings vir oorerflikheid met meer as een eienskap het goed vergelyk met die beramings vir enkel-eienskap oorerflikhede. Genetiese korrelasies tussen gewigseienskappe het gewissel van 0.04 vir geboortegewig en jaaroudgewig tot 0.81 vir speengewig en jaaroudgewig. Lae tot matige genetiese korrelasies tussen jaaroudeienskappe was in ooreenstemming met vorige literatuur vir wolrasse. Genetiese tendense het gunstige, maar uiters stadige genetiese vordering getoon. Genetiese- en omgewingsparameters en tendense vir vroeë groei eienskappe en lamoorlewing in die Dormerkudde is met data van 1943 tot 2019 ondersoek. Data vir jaaroudgewig en woleienskappe is oor 'n korter tydperk van 2008 tot 2018 aangeteken. Direkte enkel-eienskap oorerflikheidsberamings was 0.15 vir geboortegewig, 0.06 vir speengewig, 0.02 vir lamoorlewing, 0.19 vir jaaroudgewig, 0.63 vir skoonopbrengs, 0.56 vir skoonvaggewig, 0.59 vir stapellengte, 0.59 vir stapelsterkte, 0.60 vir KV van veseldikte en 0.80 vir veseldikte. Die maternale effek van die moeder was 0.21 vir geboortegewig, 0.08 vir speengewig en 0.06 vir jaaroudgewig. Genetiese korrelasies tussen gewigseienskappe was laag tussen geboortegewig en jaaroudgewig (0.11) en baie hoog vir speengewig en jaaroudgewig (0.93). Genetiese korrelasies tussen woleienskappe was meestal laag. Genetiese tendense vir alle gewigseienskappe dui op beduidende positiewe tendense met verloop van tyd. Relatief tot die algehele fenotipiese gemiddelde, het hierdie tendense 0.12% vir geboortegewig, 0.16% vir speengewig en 0.45% vir jaaroudgewig beloop. Seleksie vanaf 2013 vir direkte-, maternale- en 'n kombinasie van direkte en maternale teeltwaardes tot en met 2019 het gelei tot genetiese tendense van 0.07% vir geboortegewig, 0.79% vir speengewig en 1.01% vir jaaroudgewig in die lyn wat geselekteer is vir direkte teeltwaardes vir speengewig. Ooreenstemmende genetiese tendense was onderskeidelik -0.51%, 0.17% en 0.27% in die lyn wat geselekteer is vir maternale teeltwaardes vir speengewig en onderskeidelik -0.20%, 0.41% en 0.58% in die lyn wat gekies is vir 'n kombinasie van direkte- en maternale teeltwaardes. Maternale genetiese tendense was aansienlik kleiner, selfs in die lyne wat vir maternale teeltwaardes geselekteer is. Die rasvergelykingsresultate het gedui daarop dat SAVM-lammers swaarder was by geboorte in vergelyking met hul Dormer-tydgenote (4.19 vs. 4.13 kg). Dormers

was swaarder as SAVMs by speen (27.3 vs. 25.0 kg) en ook by jaaroud (49.7 vs. 47.8 kg). Dormerlammers het beter oorleef as SAVM's, met onderskeidelik 0.89 en 0.81 lammers gespeen per lam gebore. Skoonvaggewig was die enigste woleienskap wat nie deur die ras beïnvloed is nie. Jaaroud Dormers het hoër skoonopbrengs en stapellengte waardes as SAVM's gehad. Daarenteen het jaaroud SAVM's 'n laer KV van veseldikte en fyner wol (onderskeidelik 22.4 vs. 28.6 µm) gehad as hul Dormer tydgenote. Die twee rasse het nie vir slaggewig, karkasgewig of uitslagpersentasie verskil nie. Dormers het 'n dikker onderhuidse vetbedekking op die kruis gehad as SAVM tydgenote (5.00 vs. 4.18 mm). Daar is tot die gevolgtrekking gekom dat alle eienskappe wat oorweeg is, veranderlik en oorerflik was, alhoewel response op seleksie by eienskappe soos lamoorlewing en speengewig by SAVMs stadig kan wees. Rasverskille vir ekonomies belangrike eienskappe stem ooreen met die rolle van die twee rasse, met die Dormer as 'n growwe wol terminale ramras en die SAVM as 'n dubbeldoelras.

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Preface

This thesis is presented as a compilation of 7 chapters. After a General Introduction, each of five research chapters are introduced separately and is written according to the style of the peer-reviewed local South African Journal of Animal Science. These chapters are followed by a General Conclusions and Recommendations chapter, synthesizing the outcomes of the foregoing research chapters. The thesis therefore represents a compilation of manuscripts, where each research chapter is an individual entity.

Chapter 1 **General introduction and project aims**

Chapter 2 **Research chapter**
Genetic and environmental parameters and trends for early growth and yearling traits of the Elsenburg South African Mutton Merino resource flock

Chapter 3 **Research chapter**
Genetic and environmental parameters and trends for early growth and yearling traits of the Elsenburg Dormer resource flock

Chapter 4 **Research chapter**
Responses to selection on direct and/or maternal breeding values for growth traits of Elsenburg Dormer sheep

Chapter 5 **Research chapter**
Differences in growth, wool traits and lamb survival of South African Mutton Merino and Dormer sheep in the same environment

Chapter 6 **Research chapter**
Differences in carcass and meat quality traits of South African Mutton Merino and Dormer sheep in the same environment

Chapter 7 **General conclusions and recommendations**

Outputs

The following papers have been published in peer-reviewed accredited journals and conference proceedings:

- Muller, A., Brand, T.S., Cloete, J.J.E. & Cloete, S.W.P., 2019. Growth, carcass and meat quality traits of Dormer and South African Mutton Merino lambs. Proc. Assoc. Advmnt. Anim. Breed. Genet. 23, 119-122.

- Muller, A., Brand, T.S., Scholtz, A.J., Kruger, A.C.M. & Cloete, S.W.P., 2020. Genetic and environmental parameters and trends for early growth and yearling traits in the Elsenburg Dormer resource flock. Small Rumin. Res. 191, 106181 https://doi.org/10.1016/j.smallrumres.2020.106181

The following work from this study has been presented as oral presentations at national and international scientific meetings:

- Muller, A., Cloete, S.W.P., Kruger, A.C.M., 2019. Estimation of genetic parameters and trends of growth traits and lamb mortality in the Elsenburg Dormer resource flock. *51st South African Society of Animal Science Congress.* 10-12 June 2019. University of the Free State, Bloemfontein, South Africa.

- Muller, A., Brand, T.S., Cloete, J.J.E., Cloete, S.W.P., 2019. Growth, carcass and meat quality traits of Dormer and South African Mutton Merino lambs. *23rd Association for the Advancement of Animal Breeding and Genetics Conference*, 27 Oct to 1 Nov 2019. *Delegate Booklet*, p33. University of New England, Armidale, New South Wales, Australia.

List of abbreviations

BLUP	Best Linear Unbiased Prediction
BW	Birth weight
c^2	Permanent maternal environmental ratio
CFW	Clean fleece weight
CV	Coefficient of variation
CVFD	Coefficient of variation of fibre diameter
CY	Clean yield
DECRA	Departmental Ethics Committee for Research on Animals
E	East
FD	Fibre diameter
GPS	Global Positioning System
h^2	Direct additive heritability
ha	Hectare
kg	Kilogram
km	Kilometre
l^2	Litter size ratio
LH	Luteinizing hormone
LS	Lamb survival
LSM	Least square means
m^2	Maternal additive heritability
mm	Millimetre
n	Number of records
N/ktex	Newtons/kilotex
r	Correlation coefficient
r^2	Coefficient of determination
r_{am}	Genetic correlation between animal effects
r_c	Maternal permanent environmental correlation
r_e	Environmental correlation
r_l	Litter correlation
r_g	Genetic correlation
r_m	Maternal correlation
r_p	Phenotypic correlation
SAMM	South African Mutton Merino
SAVM	Suid-Afrikaanse Vleismerino
S	South
SD	Standard deviation
SE	Standard error
SL	Staple length
SS	Staple strength
WW	Weaning weight
YW	Yearling weight
µm	Micrometre
σ^2_a	Direct additive variance
σ_{am}	Covariance between animal effects
σ^2_c	Permanent maternal environmental variance
σ^2_l	Litter size variance

σ^2_m	Maternal additive variance
σ^2_p	Total phenotypic variance
%	Percent
b	Regression coefficient (mostly in association with a genetic trend)

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Chapter 1
General introduction and project aims

1.1 Background

Although relatively small compared to other livestock industries such as broilers, beef, dairy and poultry, the small stock industry is of crucial economic importance to the South African livestock industry and rural stability (Cloete *et al*., 2014). Over the past years South African sheep farmers have been faced with rapid changes in consumer demands regarding meat consumption, diet preferences and ethical production practices. Fluctuations in the ratio between wool and meat prices have resulted in the emphasis on the two products constantly changing in recent times (Olivier, 1999; Huisman *et al*., 2008). Sheep breeding programs need to effectively implement changes to meet the changing demands of consumers, changing environments and economic realities (Van Wyk *et al*., 2003). Reproduction plays an important role in the South African sheep industry, as meat typically contributes largely to the income of wool farmers (Olivier, 1999). Also, accurate environmental and genetic parameter estimates for breeds are needed before changes are made to selection criteria to accommodate these factors and changes. This thesis updates previous literature and presents novel analyses on wool traits in the Elsenburg SA Mutton Merino (SAMM) and Dormer flocks. Both flocks are recognized as the foundation flocks of the respective breeds. The SAMM has developed as a prominent dual-purpose breed in South Africa, while the Dormer is the most important terminal sire breed (Cloete *et al*., 2014). It is important to introduce the respective breeds to the reader, as well as to provide a brief history of both flocks as well as the research they supported.

1.2 The SA Mutton Merino

The South African Mutton Merino (SAMM) is a dual-purpose breed that was developed from the imported German Merino by selection from the 1930s (Vosloo, 1967). During the 1930s it was recommended that the German Merino (known as the Deutsche Merinofleischschaf in Germany) should be imported to South Africa and accordingly 10 ewes and a ram were imported by the Department of Agriculture for experimental purposes during 1932 (Cloete, 1998). These animals were housed at the Elsenburg Research Farm in the Western Cape where they were used in crossbreeding and breed comparison experiments. More imports followed by the state for the flock at the Elsenburg Research Farm based on the performance of the German Merino. However, private breeders also started importing German Merinos. These imports included 6 rams and 38 ewes that were imported from 1936 to 1954 and distributed

throughout South Africa (Vosloo, 1967). According to the latter author, the German Merino was the breed of choice among many breeds tested, due to its high lambing percentage in autumn, a better wool production and improved disease resistance compared to its competitors. The breed adapted well to South African conditions especially in the winter rainfall and grassland areas.

The German Merino breeder's society was established on 30th October 1946 and was accepted by the South African Stud Book Association in 1951. Climatic conditions of South Africa differed greatly from Germany and the imported German Merinos had to adapt to the extensive, semi-intensive and more intensive farming conditions commonly practiced in South Africa. Their conformation and short dry and yellow wool would still undergo major changes through selection. Subsequent within breed selection and branding of the breed with emphasis on its mutton (fleisch) production capacity rendered it suitable for its present dual-purpose role. However, dedicated breeders also contended that the locally developed breed diverged from its German Merino ancestors. Therefore, the name SAMM was adopted by breeders in 1970. This breed was developed to produce lambs of good slaughter weight at an early age, as well as to still produce apparel wool of a good quality.

The breed was initially known for its fertility while producing a medium to strong white apparel wool of between 22 and 23 microns, which is over-crimped when compared to Merino wool of the same diameter. The SAMM breed is an efficient feed converter and does extremely well in feedlot and pasture systems because of its ability to utilize low quality roughage (South African Mutton Merino Breeders' Society, 2009; Van der Merwe, 2020; Zemuy, 2002). It is known for its non-selective grazing habits and causes minimal trampling of pastures (Zemuy, 2002). It utilizes its energy efficiently and therefore leads to optimal wool and meat production, especially in grain producing areas of South Africa (Burger *et al.*, 2013; Van der Merwe, 2020). It is well adapted for all climatic conditions and is known for its strong constitution (Neser *et al*., 2000). This dual-purpose breed excels in crossbreeding programs with woolled breeds because of its advantageous conformation, hardiness, fertility and adaptability (Cloete *et al*., 2005). The SAMM breed contributed to the development of recent composite breeds in South Africa including the Dormer, Dohne Merino and Afrino, while seed stock has also been exported to other countries, including Australia (Van der Merwe, 1976; Snyman *et al*., 1995; Cloete *et al*., 2001).

Vosloo (1967) was the first to publish a dissertation on the production and reproduction traits of German Merinos. Neser *et al*. (2000) estimated non-genetic factors and genetic parameters for several growth traits using 387600 pedigree and 126477 performance records from the national SAMM database over a 25-year period from 1974 to 1999. Breeders record

weights at different ages and do not regularly supply all the records to the database, limiting studies using field data. However, this study provided useful information on operational models and genetic parameters for predicting breeding values that is important for usage during selection.

Zemuy (2002) used ASREML to derive genetic parameters for early growth traits (birth and weaning weight) as well as phenotypic and genetic parameters for yearling weight and wool traits including greasy and clean fleece weight and fibre diameter for the Elsenburg SAMM flock. Genetic and environmental trends for all the traits were also estimated. These studies were carried out from 1955 to 2002 and concluded that non-genetic factors were important sources of variation in weight and wool traits. These studies also indicated the importance of model specification regarding the fixed as well as the random part of the model for estimating genetic parameters and breeding values. It was observed that heritability estimates for birth and weaning weight were low while the heritability for yearling weight were moderate and high for wool traits. Genetic improvement by selection for these traits should thus be easier to achieve. It was also found that correlated responses to selection for most traits will be slow. Genetic gain for all the traits seemed to be small over the 44-year study period as selection for growth and wool traits were not primary selection objectives in the flock (Zemuy, 2002). The small positive genetic trends that were observed could be ascribed to correlated responses to selection for visually assessed traits such as conformation.

The study of Neser *et al*. (2000) mostly focused on the estimation of (co)variance components for early live weight and growth of SAMM sheep whereas Cloete *et al*. (2001) included SAMM sheep of the Stellenbosch University's Mariendahl flock for the estimation of genetic variance ratios for yearling weight and wool traits (only clean fleece weight and fibre diameter). Cloete *et al*. (2004b) subsequently estimated genetic and environmental (co)variance components and ratios for yearling weight and wool traits in the Elsenburg SAMM resource flock and suggested that their study laid the foundation for wool to be emphasized in future selection strategies. The present study used updated databases for a more comprehensive analyses on early live weight, survival and wool traits yet on the flock.

1.3 Dormer

The Dormer breed was developed in the 1940's at the Elsenburg Research Farm, near Stellenbosch in the Western Cape. Dorset Horn rams were crossed with German Merino ewes with the objective to establish a composite, synthetic breed (Cloete, 1998). The Dormer is known as a coarse wool breed and displays favourable growth and meat production

characteristics (Van der Merwe *et al*., 2019). The Dormer became an important terminal sire breed for usage on wool breed ewes in South Africa (Zishiri *et al*., 2010; Cloete *et al*., 2014). The Elsenburg flock was initially evaluated by Van der Merwe (1976) and then by Van Wyk *et al*. (1993a, b, c, d, e). Each evaluation had more data available and the latter studies used updated techniques for the analyses. No animals were introduced into the flock until after the second study, which led to an increase in inbreeding as the original cross between Dorset Horn rams and German Merino ewes were from unrelated breeds.

Van Wyk *et al* (1993a) investigated the importance of non-genetic sources of variation on early growth traits. While, Van Wyk *et al*. (1993b) estimated variance components and heritabilities for early growth traits in the Elsenburg Dormer resource flock using REML procedures. During the study of Van Wyk *et al*. (1993d) the genetic, phenotypic and environmental correlations among early growth traits were also evaluated. The genetic change in early growth traits were assessed in the closed Elsenburg breeding population by portioning the phenotypic trend into its casual components, i.e. the genetic and the environmental trends (Van Wyk *et al*., 1993e). Furthermore, the resource flock was closed from outside genetics from 1941 to 1997, therefore, the effect of inbreeding was initially documented by Van Wyk *et al*. (1993c). Van Wyk *et al*. (2009) subsequently quantified the effect of increasing in the actual level of inbreeding, the effect of inbreeding depression and the effect of ignoring inbreeding vs. considering inbreeding coefficients of the animal and dam on (co)variance estimates and breeding values for early growth and reproduction traits.

Fair (2002) compared the methodology used by previous authors to REML procedures for the Elsenburg Dormer flock. He also updated the genetic parameter estimates for the Dormer resource flock in a study that was crucial especially due to the inevitable increase in inbreeding. Although Van der Merwe (1976) evaluated reproduction, the methods had become outdated. Therefore, the study by Fair (2002) re-estimated genetic parameters for reproduction traits as was eventually published by Van Wyk *et al*. (2003).

None of the previous studies considered post weaning weights as well as yearling wool traits in the breed. Given that wool is not considered an important product in the breed, this is not surprising. However, data recorded since 2007 allowed this thesis to be the first study to report genetic and environmental parameters and trends for yearling live weight and wool traits in the breed. It thus makes an important contribution to the existing literature on the Elsenburg flock, as well as to the literature on the breed. The study also reports the impact of targeted selection for direct and/or maternal breeding values for weaning weight on realized genetic responses in the breed for the first time.

1.4 Studies involving comparisons of the two breeds

Improved reproduction rate in sheep, especially in slaughter lamb production systems, is of utmost importance. Therefore, Kritzinger *et al*. (1984a, b, c) compared selection criteria in the Elsenburg Dormer and SAMM flocks as a means of improving reproduction rate. Selection criteria that were used were birth type and early reproductive performance of females in one study, luteinizing hormone (LH) concentrations in the serum of prepubertal lambs and lastly prepubertal testis size of male lambs. It was observed that positive gains in reproductive performance could be accomplished using selection based on the ewe's birth type and her early reproductive performance but not using LH levels in lambs and testis diameter of male lambs. As selection on birth type used a single maternal record for reproduction of ewes, this concept was extended by Cloete *et al*. (2004c) to include a ranking value based on all available records of the dam in question. This approach led to marked divergent responses in discrete reproduction traits when selection was practiced for and against number of lambs weaned per ewe mated in the latter study on Elsenburg Merinos.

Lamb mortality is considered as an important source of reproductive inefficiency in sheep production systems (Alexander, 1984). The majority of lamb deaths are expected during the perinatal period described as the period shortly before, during and within seven days of birth. Cloete (1992) initially investigated the ease of birth, post parturient maternal behaviour and separation of ewes from one or more viable lambs in relation to lamb mortality of Dormer and SAMM lambs. Cloete (1993) also reported on the neonatal progress of Dormer and SAMM lambs by investigating birth weight and behavioural traits with possible survival value in the offspring of fecund ewes observed continuously during lambing. Cloete (1994) furthermore studied the ewe rearing performance in 4 experimental flocks in the Western and Southern Cape regions, including Dormers and SAMMs. This study related rearing performance to pelvic dimensions to determine the contribution of ewe pelvic size to repeated rearing failure. It was observed that rearing performance could be improved by selection and is likely to improve productivity without markedly influencing input costs, resulting in meaningful economic gains for producers. Cloete *et al*. (1993) further investigated the causes of perinatal lamb mortality amongst Dormer and SAMM lambs. Causes could include stressful birth and starvation-mismothering-exposure (SME) syndromes, ante-parturient deaths, infections, predation and congenital defects. Birthing difficulty is widely regarded as economically important and were reported to differ between sheep breeds (Haughey, 1991; Cloete, 1992; Jacobson *et al*., 2020) although the relationship between pelvic dimensions and rearing performance was found to also differ between breeds (Cloete, 1994). Therefore, birth difficulty in Dormer and SAMM sheep was investigated including information regarding pelvic dimensions, litter size and weight, as well as conformation in relation to length of parturition (Cloete *et al*., 1998). Differences in the

mechanisms involved in the birth process were observed between the two breeds although ease of parturition could not be predicted with reasonable accuracy. This study reported the mechanisms associated with difficult birth in the respective breeds and the mechanisms underlying the breed difference in favour of Dormers, as reported previously (Cloete, 1992). This breed difference contributed to a difference in total lamb survival in favour of Dormers that was initially reported by Brand *et al*. (1985).

The study of Cloete *et al*. (2002) continued to investigate genetic and environmental (co)variances on lambing and neonatal behaviour of Dormer and SAMM lambs. However, it was not possible to estimate direct and maternal (co)variances for lambing and neonatal behaviour in sheep. It was furthermore evident in this study that lamb mortality was related to breeding values for these behavioural traits in lambs, suggesting that there is a genetic association between these traits. Therefore, it was suggested that selection for lamb survival could result in improvements in associated behaviour traits.

Neser *et al*. (2000) argued that the Dormer breed is early maturing and deposits fat early, whereas the SAMM breed is late maturing and thus deposits fat at an older age. Therefore, in lambs slaughtered at the same age, SAMM sheep should have deposited less fat than Dormers (Van der Westhuizen, 2010). Cloete *et al*. (2004a) compared the body composition, carcass characteristics and retail cuts of Elsenburg SAMM and Dormer progeny. These results agreed with the original production objectives of the breeds and concluded that the SAMM breed excel in commercial production of meat and wool whereas the Dormer breed is suitable for terminal crossbreeding to increase meat production potential in crossbred progeny. Hoffman *et al*. (2003) investigated the influence of ewe (Merino, Dohne Merino and SAMM) and sire (Dormer or Suffolk) breeds on the sensory, physical and nutritional quality characteristics of lamb. They showed that the breeding of wool-type ewes to mutton ram breeds will not have a negative influence on meat quality. Cloete *et al*. (2012) compared the slaughter and meat quality traits of wool, dual-purpose and meat breeds (Merino, Dohne Merino, SAMM and Dormer) that were reared on the same pasture and slaughtered at the same age. This study also suggested that early-maturing breeds are generally fatter at the same age compared to late-maturing breeds. According to Van der Merwe *et al*. (2019) both the SAMM and Dormer breeds are regarded as medium maturing, have a high growth rate and grow out to a high mature weight. Van der Merwe *et al*. (2020) compared the carcass composition and physical meat quality characteristics of female and male lambs from seven different South African sheep breeds, including the SAMM and Dormer, which were feedlot-finished. This study reported that differences in carcass weights for different breed types could be ascribed to the breed effects on the onset of fat deposition. Thus, slaughtering lambs of different breeds at the same degree of fatness will result in rearing lambs for different periods because of variation in carcass size

and conformation, although meat quality characteristics will still be similar (Van der Merwe *et al*., 2020).

The previous studies by Cloete *et al*. (2004a; 2012) and Van der Merwe *et al*. (2019; 2020) were carried out using relatively small databases and sample sizes. Moreover, the animals reported on by Cloete *et al*. (2004a; 2012) were not slaughtered at a realistic slaughter age for carcass and meat quality traits. In contrast, the studies by Van der Merwe *et al*. (2019; 2020) were on concentrate-fed lambs under feedlot conditions. No large-scale comparison of meat traits in the two breeds is available at present, possibly because meat traits are not routinely recorded in official records for the breeds (Schoeman *et al*., 2010). Furthermore, no previous research has been done on comparing yearling weight and wool traits of these breeds.

1.5 Aim and Objectives

The aim of this study was to estimate environmental and genetic parameters of the Elsenburg Dormer and SAMM flocks for all traits, to assess response to selection and to compare these two flocks for economically important traits.

Against this background, the primary objective of this study were to estimate updated and novel genetic and environmental parameters and trends for growth, lamb survival and yearling wool traits separately in the Elsenburg SAMM and Dormer resource flocks (respectively in Chapters 2 and 3). A second objective was to evaluate direct and correlated responses to selection for direct and/or maternal breeding values for lamb weaning weight in the Elsenburg Dormer flock (Chapter 4). The third objective were to compare the two breeds for differences in lamb survival, growth and yearling live weight, wool, slaughter and meat quality traits maintained on the same pasture and raised in the same environment (Chapters 5 and 6).

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Chapter 2
Genetic and environmental parameters and trends for early growth and yearling traits of the Elsenburg South African Mutton Merino resource flock

Abstract

The Elsenburg South African Mutton Merino (SAMM) resource flock has been maintained at the Elsenburg Research Farm in the Western Cape, South Africa since 1955. Early growth and lamb survival data over the 64-year period (1955 - 2019) and yearling weight and wool data over a 36-year period (1983 - 2019) were used to estimate genetic and environmental parameters and trends for the SAMM breed. ASREML were used to estimate fixed effects and genetic parameters and trends in the resource flock. Birth year, sex, birth type and age of dam significantly influenced the weight traits and lamb survival. The interaction between birth year and sex was evident in most early growth traits. Direct single-trait heritability estimates amounted to 0.07 for birth weight (BW), 0.03 for weaning weight (WW), 0.02 for lamb survival (LS), 0.24 for yearling weight (YW), 0.58 for clean yield (CY), 0.37 for clean fleece weight (CFW), 0.34 for staple length (SL), 0.55 for coefficient of variation of fibre diameter (CVFD) and 0.68 for fibre diameter (FD). Maternal heritability estimates were 0.15 for BW, 0.06 for WW and 0.01 for LS. Dam permanent environmental effects amounted to 0.07 for BW, 0.04 for WW, 0.03 and 0.04 for LS, respectively, whether birth weight was included in the model or not, 0.08 for YW and 0.05 for CFW. Litter effects amounted to 0.21 for BW, 0.19 for WW and 0.13 for LS. Multi-trait heritability estimates compared well with the single-trait estimates. Genetic correlations for the weight traits in the three-trait analyses ranged from 0.04 for BW and YW to 0.81 for WW and YW. The phenotypic and environmental correlations of the weight traits corresponded well with each other. Genetic, environmental and phenotypic correlations amongst yearling weight and wool traits in the six-trait analyses were low to moderate and mostly within the ranges from previous literature for wool breeds. Genetic trends for all the traits were heritable and showed positive but extremely slow genetic progress that ranged from -0.023% for CVFD to 0.088% for YW expressed as a percentage of the overall phenotypic mean. Although adequate genetic variation was present in the SAMM flock especially for yearling traits, realised genetic progress was slow.

2.1 Introduction

The South African Mutton Merino (SAMM) breed is the second most important dual-purpose breed in South Africa (Cloete *et al*., 2016), being bred both for meat and wool. South

African Mutton Merino weaning weights submitted for national performance recording almost tripled from 2005 - 2008 to 2010 - 2011 (Cloete *et al*., 2014). The SAMM breed originated from the German Merino which was imported to South Africa in 1932. The breed adapted well to South African conditions which led to further imports in 1936, 1937, 1949 and 1954 (Vosloo, 1967). The first imports of the German Merino were maintained at the Elsenburg Research Farm in the Western Cape, from where it spread throughout South Africa. The breed played a major part in the development of composite breeds, including the Dohne Merino, Dormer and Afrino (Van der Merwe, 1976; Snyman *et al*., 1995b; Cloete *et al*., 2001b). The SAMM has also been exported as seed stock to countries aboard, among others to Australia (Cloete *et al.,* 2001b). The global distribution of the SAMM prompts the need for updated genetic evaluations in the breed.

Breeding objectives for apparel wool sheep are complicated by fluctuations in sheep meat and wool prices as well as the increasing global demand for lamb. Moreover, consumer preferences call for sustainable and ethical production practices (Banhazi *et al*., 2012). This implies that, apart from traits such as the quality and quantity of meat and wool produced, other contributing traits such as lamb survival, disease resistance, feed intake, behaviour and conformation should also be considered. It is thus essential to have information on genetic parameters for all traits, including lamb survival (Cloete *et al*., 2009). Therefore, breeding programmes aimed at improving these economically important traits requires knowledge of genetic (co)variances for and among traits (Safari *et al*., 2005). Previously, emphasis was placed on subjectively assessed wool and conformation traits when selecting SAMM sires and dams. This practice could be to the detriment of economically important traits such as objectively measured live weight, wool and reproduction traits (Matebesi *et al*., 2009). Knowledge of genetic relationships of these traits with economically important weight and wool traits are crucial to understand how selection for these traits will influence traits of economic importance (Gregory, 1982).

Vosloo (1967) was the first to publish a dissertation on production and reproduction traits of German Merinos. Neser *et al.* (2000) estimated (co)variance components for early live weight and growth using performance testing data in SAMM sheep. Cloete *et al*. (2001b) reported genetic variance ratios for yearling live weight, clean fleece weight and fibre diameter in SAMM sheep maintained on the Mariendahl Experimental Farm of Stellenbosch University from 1980 to 1994. Cloete *et al*. (2004) subsequently estimated genetic and environmental (co)variances for yearling live weight and fleece traits of the SAMM flock at Elsenburg, also the subject of this study. All these studies were based on a relatively small datasets, sometimes with structural imperfections. Otherwise, there has been very little research done on variance estimates for

yearling weight and wool traits of the SAMM breed, since wool traits are not officially recorded in the breed (Schoeman *et al*., 2010).

Against this background, the aim of this study was to update the estimates for genetic and environmental parameters for early growth and yearling traits and also to estimate genetic parameters for lamb survival in a comprehensive account of the genetics of the Elsenburg SAMM flock over a 64-year period.

2.2 Materials and methods

2.2.1 Animal resources, the environment and management

The Elsenburg SAMM resource flock was maintained on the Elsenburg Research Farm during the time of data collection (Cloete *et al*., 2004). The records for this study was obtained from the fully pedigreed stud, situated 10 km north of Stellenbosch (33^0 51' S, 18^0 30' E) in the Western Cape. The elevation at Elsenburg is 177 m above sea level. The climate is Mediterranean with an average annual precipitation of 642 mm, of which most (78%) is expected between April and September.

The Elsenburg SAMM flock was established in 1955 and the flock consisted of about 150 breeding ewes on average per year (64 years). Numbers have recently been allowed to decrease to about 60-80 breeding ewes.

The ewes grazed on irrigated kikuyu (*Pennisetum clandestinum*) paddocks of approximately 0.5 ha in size during joining and lambing. Since 1989, the Elsenburg SAMM and Dormer flocks (see Chapter 3) were managed in a single population, initially to allow the studies on ewe and lambing behaviour up to 1998 (Cloete *et al*., 2002), and since to compare the breeds under similar conditions (see Chapters 4 and 5). Selected rams were mated to groups of between15 and 30 ewes during October and November, using a single-sire mating system. They subsequently also lambed in these kikuyu paddocks the following year during March and April together with their Dormer contemporaries (Cloete, 1992; 1993). Between 3 to 14 days after lambing the ewes and lambs were moved to irrigated lucerne (*Medicago sativa*) paddocks in groups consisting of 30 and 40 ewes and lambs. Later on, these groups were joined to form a larger flock, which grazed on dryland lucerne and occasionally oat (*Avena sativa*) fodder crops. It was attempted to standardise the management practices in the flock as far as possible during this time, although changes owing to the climate, available infrastructure and responsible officers, were inevitable over the 64-year period.

2.2.2 Data recorded and selection practices implemented

Lambs were identified together with their dams and weighed within 24 hours of birth (Cloete *et al*., 1993). Weaning took place at an average (± SD) age of 103 ± 8 days and thereafter the lambs were separated on sex and maintained in different paddocks. Lamb survival, as a trait of the lamb, from birth to weaning was derived from birth and rearing data. All lambs were shorn for the first time during September and October at 5 to 6 months of age and again during February or March of the following year as yearlings at 342 ± 42 days. After shearing the lambs were weighed to collect the yearling weights. Greasy fleece weight was recorded, and a mid-rib wool sample was taken to determine clean yield, staple length, coefficient of variation of fibre diameter and fibre diameter at the South African Wool Testing Bureau. Clean fleece weight was calculated using greasy fleece weight and clean yield data. Clean fleece weight and staple length records were adjusted from a growth period of 137 ± 9 days to a full 365-day calendar year. Selection over the study period was mostly based on a high early growth rate and subjective conformation traits. No selection pressure was applied to any of the yearling traits.

2.2.3 Statistical analysis

In common with other studies involving sheep breeding, the data used were unbalanced, requiring analysis by mixed, linear animal models. The fixed effects included were sex (male or female), birth type (single, twin or triplet), age of dam (2 - 7+ years), birth year (1955 – 2019 for early growth traits and lamb survival; 1983 – 2018 for yearling traits) and two-factor interactions between effects. Animal age was included as a linear covariate in analyses on weaning and yearling weights. Lamb survival was analysed with and without the inclusion on linear and quadratic regressions on birth weight. ASREML (Gilmour *et al*., 2016) was used for all the analyses and a *P*-value of < 0.05 was considered as significant. Fixed effects which were regarded as significant were included in the final operational models for the assessment of random effects for early growth and yearling traits.

The random terms tested for significance for the operational models of early growth traits are presented in Table 2.1. Random terms included direct additive, maternal additive, dam permanent environmental and litter effects, as well as the covariance between direct and maternal additive effects. Analyses on yearling traits included the same random effects, except for litter. The above combinations resulted in nine mixed, linear animal models for early growth traits and six mixed, linear animal models for yearling traits, all in matrix notation.

Table 2.1 Description of the number of models used for early growth and yearling traits for the Elsenburg SAMM flock in matrix notation.

Models	Early growth traits	Yearling traits
$y = Xb + Z_1a + e$	1	1
$y = Xb + Z_1a + Z_2c + e$	2	2
$y = Xb + Z_1a + Z_3m + e$ [Covariance (a,m)=0]	3	3
$y = Xb + Z_1a + Z_3m + Z_2c + e$ [Covariance (a,m)=0]	4	4
$y = Xb + Z_1a + Z_4l + Z_2c + e$	5	
$y = Xb + Z_1a + Z_3m + Z_4l + Z_2c + e$ [Covariance (a,m)=0]	6	
$y = Xb + Z_1a + Z_3m + e$ [Covariance (a,m)=$A\sigma_{am}$]	7	5
$y = Xb + Z_3a + Z_3m + Z_2c + e$ [Covariance (a,m)=$A\sigma_{am}$]	8	6
$y = Xb + Z_3a + Z_3m + Z_2c + Z_4l + e$ [Covariance (a,m)=$A\sigma_{am}$]	9	

In these analyses, y = a vector of observations for the respective traits, b = a vector of fixed effects, a = the direct genetic variance, m = the maternal genetic variance, c = the dam permanent environmental variance, l = the litter variance, X, Z_1, Z_2, Z_3 and Z_4 = the corresponding incidence matrices relating the respective effects to y, e = a vector of residuals, A = the numerator relationship matrix and σ_{am} = the covariance between direct genetic and maternal genetic effects.

It was assumed that:

$$V(a) = A\sigma^2_a;\ V(m) = A\sigma^2_m;\ V(c) = I\sigma^2_c;\ V(l) = I\sigma^2_l;\ V(e) = I\sigma^2_e$$

Where, A = the numerator relationship matrix denoting relationships among animals in the pedigree file, I = identity matrices relating other random terms to the data, σ^2_a = the direct genetic variance, σ^2_m = the maternal genetic variance, σ^2_c = the dam permanent environmental variance, σ^2_l = the litter variance and σ^2_e = the environmental (residual) variance. The pedigree file used in the analyses included 13214 animals, the progeny of 313 sires and 2311 dams.

Random effects for both early growth and yearling traits were tested for significance using log likelihood ratio tests after the sequential inclusion of the random terms in Table 2.1 to the operational model for each trait. A random effect was regarded as significant when its inclusion in the model caused a significant improvement in the log likelihood ratio. The Chi-square distribution of α = 0.05 at one degree of freedom was used as a test statistic (3.841). When -2 times the difference between the log likelihoods was greater than this critical value, the inclusion of the particular random effect was considered to improve the fit ($P < 0.05$; Swalve, 1993). Various models were tested for significance to identify the best and simplest models that could be used for subsequent multi-trait runs. A three-trait analysis was conducted to estimate the

genetic, phenotypic and environmental correlations for the weight traits. A series of multi-trait analyses were then conducted to estimate the genetic, phenotypic and environmental correlations among yearling weight and the wool traits.

Direct and maternal animal solutions from multi-trait models were obtained from the analyses and used to derive direct and maternal genetic trends, where applicable. Individual breeding values were regressed on birth years to reflect the accrued genetic gains for each trait. Ethical clearance for this study was obtained from Departmental Ethics Committee for Research on Animals (DECRA) of the Western Cape Department of Agriculture, reference number – R12/55.

2.3 Results and discussion

2.3.1 Descriptive statistics

Table 2.2 contains the descriptive statistics for the early growth and yearling traits. The traits analysed over the entire 64-year period included birth weight, weaning weight and lamb survival. Yearling weight, clean yield, clean fleece weight, staple length, CV of fibre diameter and fibre diameter were recorded for progeny that were born between 1983 and 2018.

Table 2.2 Descriptive statistics of early growth and yearling traits in the Elsenburg SAMM flock.

Trait	n	Mean	SD	CV (%)	Range
Early growth traits					
Birth weight (kg)	12904	4.3	0.91	21.4	0.7 - 7.5
Weaning weight (kg)	9021	27.3	6.16	22.6	7.0 - 50.9
Lamb survival ratio	12938	0.72	0.45	62.5	0 - 1
Yearling traits					
Yearling weight (kg)	3156	49.7	9.17	18.5	23.0 - 86.0
Clean yield (%)	3361	66.6	5.88	8.8	50.8 - 83.8
Clean fleece weight (kg/12 months)	3317	2.1	0.55	26.7	0.8 - 4.3
Staple length (mm)	2125	94	16	17.4	47 - 146
CV of fibre diameter (%)	1215	17.9	2.1	11.7	11.9 - 26.0
Fibre diameter (µm)	2603	22.9	1.68	7.3	17.1 - 28.8

n: number of records; SD: standard deviation; CV: coefficient of variation

The data recorded over the 64-year period ranged from 9021 records for weaning weight to 12938 for lamb survival with CVs of 21.4% for birth weight to 62.5% for lamb survival. The records for yearling traits ranged from 1215 for CV of fibre diameter to 3361 for clean yield. The CVs for yearling traits ranged from 7.3% for fibre diameter to 26.7% for clean fleece weight. Neser *et al.* (2000; 2001) reported slightly higher CVs of 24.2% for SAMMs and 24.7% for Dorpers for weaning weight. Cloete *et al.* (2004) used fewer records from the same flock to derive CVs for yearling traits that corresponded well with the current study, namely: 18.5% for

yearling weight, 8.9% for clean yield, 27.0% for clean fleece weight and 7.4% for fibre diameter. Cloete *et al*. (1998a) published descriptive statistics for Dohne Merinos with fewer records and reported CVs that were mostly lower than in the present study, namely: 18.5% for birth weight, 20.6% for weaning weight, 20.1% for clean fleece weight, 12.8% for staple length and 6.9% for fibre diameter. The exceptions were CVs of 18.3% for yearling weight and 9.4% for clean yield, which corresponded well with those in the current study. The CVs for early growth traits were in accordance with those for the Elsenburg Dormer flock, namely 21.9% for birth and weaning weight as well as 46.3% for lamb survival (Van Wyk *et al*., 2003). Cloete *et al*. (2001b) reported CVs for SAMMs for weaning weight, yearling weight, clean fleece weight and fibre diameter as 21.1, 19.3, 18.8 and 6.3%, respectively. The same study reported CVs for Dohne Merinos as 21.9, 20.4, 19.0 and 7.3%, respectively, and 25.0, 22.3, 21.9 and 6.8%, respectively, for Merinos. The results from Cloete *et al*. (2001b) compared well with the current study except for the CV of clean fleece weight that was lower than in the current study. Matebesi-Ranthimo *et al*. (2017) reported CVs for wool traits of the Elsenburg Merino flock. The CV for clean yield (6.57%) and CV of fibre diameter (10.76%) were lower than in the current study whereas clean fleece weight (47.06%), staple length (33.52%) and fibre diameter (8.15%) had higher CVs. Snyman *et al*. (1995a) reported CVs of 16.43% for birth weight, 19.69% for weaning weight, 20.83% for clean fleece weight and 7.68% for fibre diameter in Afrino sheep. The CV for fibre diameter of the latter study corresponded well, whereas the CVs of the other traits were somewhat lower than that of the current study. CVs recorded by Olivier *et al*. (1995) for yearling weight (31.22%), clean fleece weight (34.01%) and fibre diameter (9.79%) of the Grootfontein Merino stud were higher than those reported in Table 2.2.

The means for the traits analysed are presented in Table 2.2. Tosh & Kemp (1994) reported a mean value of 4.5 kg for birth weight and 36.9 kg for 100-day weight of Hampshire sheep, which corresponded well with those in the current study. Cloete *et al*. (2001b) compared weaning weight (26.0, 30.1 and 32.1 kg), yearling weight (49.8, 57.9 and 65.2 kg), clean fleece weight (3.2, 2.1 and 1.6 kg) and fibre diameter (21.9, 21.8 and 23.7 µm) for Merinos, Dohne Merinos and SAMM sheep. The means from the latter study compared well with those from the current study. The means of the wool traits of the Elsenburg Merino flock amounted to 74.8% for clean yield, 2.38 kg for clean fleece weight, 76 mm for staple length, 29.1% for CV of fibre diameter and 19.3 µm for fibre diameter. The staple length and fibre diameter were lower than that of the current study whereas the other means compared well to the current study. Snyman *et al.* (1995a) reported means for birth weight, weaning weight, clean fleece weight and fibre diameter of Afrino sheep as 4.65 kg, 27.67 kg, 2.01 kg and 21.4 µm. These means corresponded well with those of the present study. Dohne Merinos as reported by Cloete *et al*. (1998a) recorded means for birth weight (4.65 kg), weaning weight (28.1 kg), clean fleece

weight (1.95 kg), clean yield (66.6%) and fibre diameter (21.8 µm) which corresponded well with values from the current study although the means for yearling weight (55.8 kg) and staple length (111 mm) were higher than that of the current study. Cloete *et al*. (2002) recorded means for Western Australian Merinos which corresponded well with yearling weight (48.3 kg) and fibre diameter (21.1 µm) but the means for clean fleece weight (3.3 kg), clean yield (70.5%) and CV of fibre diameter (23.5%) were higher than those recorded in the current study. The means of the same Elsenburg SAMM flock until 2002 with fewer records corresponded extremely well with those in the current study (Cloete *et al*., 2004). The mean of yearling weight (50.39 kg) of the Grootfontein Merino stud reported by Olivier *et al*. (1995) corresponded well with the value in the current study whereas the means for clean fleece weight (1.84 kg) and fibre diameter (23.19 µm) were respectively lower and higher.

2.3.2 Environmental effects denoted by predicted fixed effect means

Table 2.3 predicted the means of the fixed effects on sex, birth type and dam age on early growth traits and lamb survival. Birth weight was significantly affected by sex, birth type, birth year and age of dam (Table 2.3). Male lambs and singles were heavier than female lambs and multiples at birth (P <0.01). The progeny of intermediate dam age groups was heavier than those of the youngest and oldest dams. These results corresponded well with those reported for Dorper (Cloete & De Villiers, 1987), Dohne Merino (Cloete *et al*., 1998a), Dormer (Fair, 2002) and SAMM lambs (Knuth *et al*., 2018).

Weaning weight was affected by sex, birth type, birth year and age of dam (P <0.001; Table 2.3). Male lambs and singles were heavier than females and multiples at weaning. The weaning weight of the progeny increased from 2- to 5-year-old dam age groups, before decreasing thereafter. Progeny of 7+ year-old dams were the lightest at weaning. The linear regression of weaning weight on weaning age was used to adjust lamb weaning weight data for weaning age differences between years. Weaning weight increased with 0.26 kg per day of age (Table 2.3). Brash *et al*. (1994a) and Brash *et al*. (1994b) reported comparable values for Corriedale and Coopworth sheep, where weight increased with 0.10 and 0.21 kg per day of age, respectively. Weaning weight was significantly affected by an interaction between birth year and sex. This was because weaning weight differed more between males and females in some years than in others. During 2000 to 2018 the difference in weaning weight between males and females were mostly not significant, although lambs of both sexes were kept in the same paddocks as their dams and only separated based on sex after weaning. There was also an interaction between sex and birth type (P <0.01), which could be explained by the comparatively small number of triplets that were analysed compared to singles and twins. There was also an

interaction between birth year and the linear regression of weaning weight on weaning age (*P* <0.001), which could be ascribed to the differences in grazing conditions due to rainfall and management practices over the 64-year period. The results of the current study corresponded with those reported by Cloete & De Villiers (1987), Cloete *et al.* (1998a), Fair (2002), Wuliji *et al*. (2011) and Knuth *et al*. (2018) for various sheep breeds.

Table 2.3 Predicted means (±SE) depicting the fixed effects of sex, birth type and dam age on early growth traits and lamb survival in the Elsenburg SAMM flock.

Effects and levels	Birth weight (kg)	Weaning weight (kg)	Lamb survival (BW included)	Lamb survival (BW excluded)
Sex				
Male	4.29 ± 0.04	27.3 ± 0.36	0.68 ± 0.02	0.64 ± 0.02
Female	3.99 ± 0.04	25.0 ± 0.36	0.74 ± 0.02	0.67 ± 0.02
P-value	***	***	***	***
Birth type				
Singles	4.98 ± 0.04	30.4 ± 0.36	0.75 ± 0.03	0.76 ± 0.03
Twins	4.11 ± 0.04	24.9 ± 0.35	0.77 ± 0.02	0.72 ± 0.02
Triplets	3.41 ± 0.04	23.2 ± 0.39	0.61 ± 0.03	0.48 ± 0.03
P-value	***	***	***	***
Age of dam (years)				
2	3.91 ± 0.02	26.1 ± 0.13	0.75 ± 0.01	0.68 ± 0.01
3	4.25 ± 0.02	27.5 ± 0.13	0.76 ± 0.01	0.72 ± 0.009
4	4.39 ± 0.02	27.6 ± 0.13	0.76 ± 0.01	0.73 ± 0.009
5	4.38 ± 0.02	27.0 ± 0.15	0.72± 0.01	0.68 ± 0.01
6	4.34 ± 0.02	26.2 ± 0.14	0.68 ± 0.01	0.64 ± 0.009
7+	3.60 ± 0.25	22.4 ± 2.06	0.59 ± 0.14	0.47 ± 0.14
P-value	***	***	***	***
Regressions				
Birth weight (L)	-	-	0.48 ± 0.06	-
Birth weight (Q)	-	-	-0.04 ± 0.006	-
Weaning age	-	0.26 ± 0.06	-	-

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; actual significance for $P > 0.05$; BW: birth weight; L: linear regression; Q: quadratic regression

Analysing lamb survival with and without birth weight as a covariate, did not make a difference in the results obtained (Table 2.3). When birth weight was included as linear or quadratic covariates in the analysis with lamb survival, a polynomic regression of lamb survival on birth weight was noted. This trend suggested that lambs with intermediate birth weights had the highest chances of survival as was reported by Hight & Jury (1970). Female lambs had a higher survival rate from birth to weaning than male lambs (*P* <0.001). Singles and twins also survived better than triplets (*P* <0.001). The survival rate of progeny increased with dams from 2- to 4-year-old, from where it decreased. The progeny of 7+ year-old dams had the worst probability of survival (*P* <0.001). The results for birth type and age of dam were in accordance with results in a study by Lopez-Villalobos & Garrick (1999) on Romney sheep. The fixed effects

affecting lamb survival in the present study was consistent with reports by Hight & Jury (1970), Dalton *et al*. (1980) and Cloete et al. (2001a) for various sheep breeds.

All yearling traits were affected by birth year (P <0.001) and the interaction between birth year and sex (P <0.05). This interaction is presented in Figure 2.1 for yearling weight. It is evident that prior to 2000 the males predominantly were heavier at yearling age with heavier fleeces than females due to being auctioned and therefore better cared for during the growing out phase. Economic reasons caused this practice to be discontinued. The differences between the sexes were much smaller during 2000 to 2018 when compared to previous years (Figure 2.1 and 2.2). Male yearlings were mostly heavier than female yearlings throughout the study, as expected (Cloete *et al*., 1998a). Table 2.4 predicted the means of the fixed effects for yearling weight and wool traits. The linear regression of yearling weight on yearling age amounted to an average increase of 0.16 kg per day for yearling weight. Males and singles had heavier yearling weights than respectively females and multiples (P <0.001; Table 2.4). The yearling weights of the progeny of 3- to 4-year-old dams were the heaviest with the progeny of 7+ year old dams most compromised (P <0.001). Means reported for various sheep breeds (Brash *et al*., 1994a, b; Cloete *et al*., 1998a; Wuliji *et al*., 2011) corresponded well with the results of the current study. The studies of Brash *et al*. (1994a; 1994b) reported that age regressions for yearling weight amounted to respectively 0.08 and 0.11 kg per day for Corriedale and Coopworth sheep.

Female yearlings had a 2.82% higher clean yield than males (Table 2.4). The effects of birth type and age of dam were not significant for clean yield. There was a significant interaction between birth year and sex for clean yield, which shows that females continually produced a higher yield than their male contemporaries during the study period, although the magnitude of this differed (P <0.05). According to Cloete *et al*. (1998a) clean yield also showed significant differences between sexes and birth type classes for clean yield in Dohne Merinos. Wuliji *et al*. (2011) reported a higher clean yield for females than males, with non-significant differences for birth type and age of dam (P >0.05) in Romneys. Brown *et al*. (1966) however found that birth type significantly affected clean yield in Merinos. The clean fleece weight of males and singles were heavier than that of females and multiples, whereas the clean fleece weights of the progeny of dams ages 3, 4 and 6 years were the heaviest. The clean fleece weight of the progeny of 2- and 5-year-old dams were lower (P <0.001).

Table 2.4 Predicted means (±SE) of the fixed effects for yearling weight and wool traits from the Elsenburg SAMM flock.

Effects and levels	Yearling weight (kg)	Clean yield (%)	Clean fleece weight (kg)	Staple length (mm)	CV of fibre diameter (%)	Fibre diameter (µm)
Sex						
Male	52.9 ± 0.60	65.5 ± 0.15	2.05 ± 0.01	92.3 ± 0.58	17.6 ± 0.11	22.7 ± 0.05
Female	44.9 ± 0.60	67.4 ± 0.14	1.95 ± 0.01	94.9 ± 0.55	17.8 ± 0.11	22.9 ± 0.05
P-value	***	***	***	***	0.11	0.10
Birth type						
Singles	51.9 ± 0.61	66.5 ± 0.16	2.10 ± 0.01	92.2 ± 0.55	17.5 ± 0.10	22.6 ± 0.06
Twins	48.0 ± 0.59	66.6 ± 0.10	1.99 ± 0.01	93.7 ± 0.37	17.9 ± 0.07	22.9 ± 0.04
Triplets	46.7 ± 0.65	66.2 ± 0.28	1.92 ± 0.02	94.9 ± 1.27	17.7 ± 0.26	22.9 ± 0.09
P-value	***	0.50	***	*	**	***
Age of dam (years)						
2	49.3 ± 0.22	66.2 ± 0.20	1.95 ± 0.02	95.0 ± 0.76	17.5 ± 0.15	22.8 ± 0.07
3	50.3 ± 0.20	66.8 ± 0.18	2.03 ± 0.02	93.0 ± 0.71	17.4 ± 0.14	22.8 ± 0.06
4	50.2 ± 0.21	66.5 ± 0.19	2.02 ± 0.02	92.8 ± 0.72	17.8 ± 0.14	22.8 ± 0.07
5	49.7 ± 0.24	66.4 ± 0.21	1.99 ± 0.02	92.8 ± 0.76	17.8 ± 0.14	22.8 ± 0.08
6	49.4 ± 0.23	66.4 ± 0.20	2.02 ± 0.02	94.3 ± 0.80	17.8 ± 0.15	22.9 ± 0.07
7+	44.4 ± 3.47	-	-	-	-	-
P-value	***	0.09	***	*	**	0.74
Regression on age	0.16 ± 0.01	-	-	-	-	-

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; actual significance for $P > 0.05$; CV: coefficient of variation

Figure 2.2 illustrates the significant interaction between birth year and sex for clean fleece weight, with an extremely fluctuating pattern between males and females from 1983 to 2018. The same reasoning for the interaction between birth year and sex for yearling weight in Figure 2.1 could also explain this result. The studies of Brash *et al*. (1994a), Cloete *et al*. (1998a) and Wuliji *et al*. (2011) also reported that sex and birth type significantly influenced clean fleece weight. Cloete *et al*. (2001b) also showed that the fixed effects of sex, birth type and age of dam were significant for clean fleece weight of SAMMs. Only sex and birth type affected the clean fleece weight of Merinos and Dohne Merinos though (Cloete *et al*., 2001b).

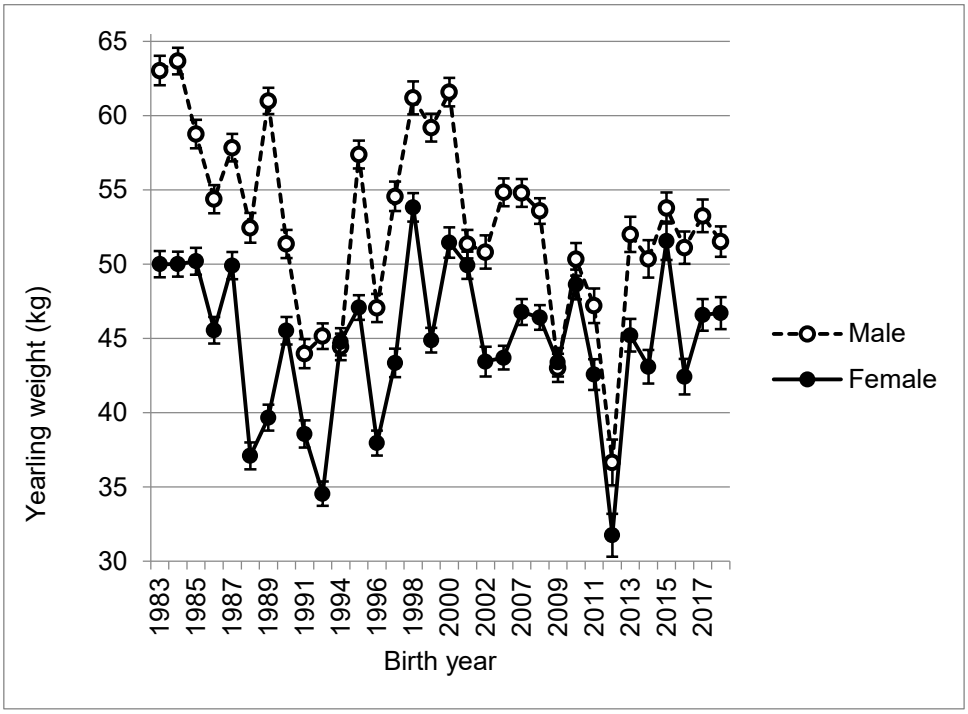

Figure 2.1 Predicted means illustrating the interaction between sex and birth year for yearling weight of the Elsenburg SAMM resource flock from 1983 to 2018. The vertical lines about means denote standard errors.

Table 2.4 illustrated 16% longer staple lengths for females compared to males (P <0.001). Muller *et al*. (2020) also reported longer staple lengths for females in Dormers. Nutrition influences wool growth and quality (Khan *et al*., 2012) and during this study females were generally allocated to better grazing conditions than males. Staple length increased from singles to triplets although the differences were very small (P <0.05). The study of Brown *et al*. (1966) reported no significant difference for staple length between singles and twins. Twins and triplets have less follicles which results in longer staples due to the nutrients being invested in less follicles per skin area (Khan *et al.,* 2012). The staple lengths from progeny of dams of different ages differed slightly with 2- and 6-year-old-dams having the longest staples and the progeny of intermediate dam age groups being lower (P <0.05). Cloete *et al*. (1998a) found that there were no significant differences among the fixed effects for staple length in Dohne Merinos. Wuliji *et al*. (2011) reported that staple length was affected by dam age in their study, whereas Brown *et al*. (1966) found that there was no difference in staple length between the progeny of maiden and adult dams of Merino sheep. The observed differences in this study did thus not represent a consistent trend and may have been coincidental.

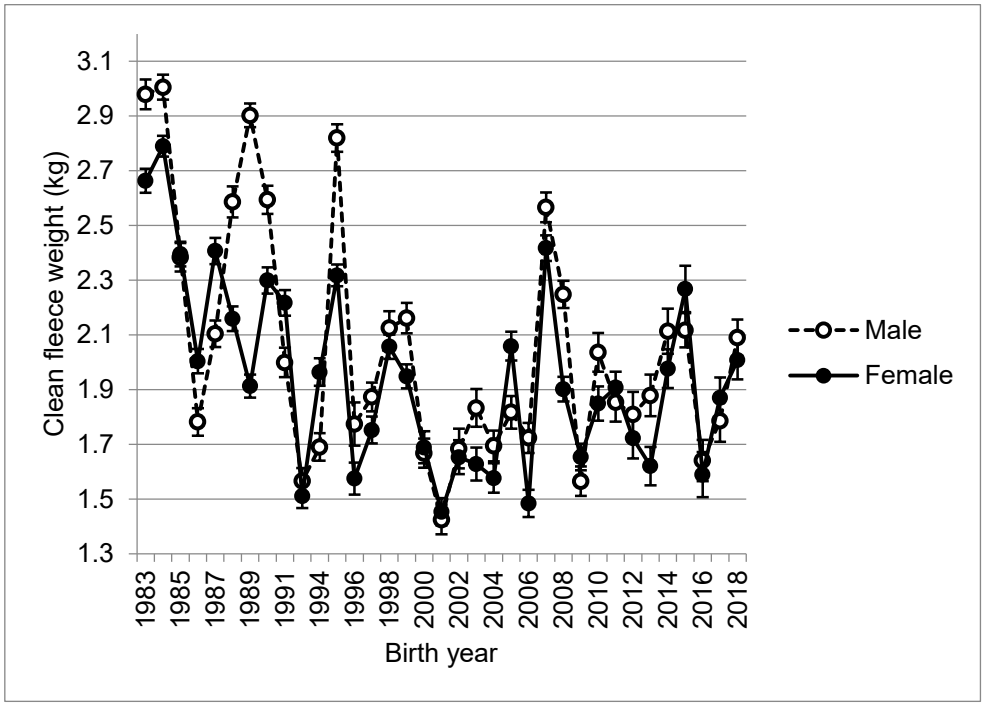

Figure 2.2 Predicted means illustrating the interaction between sex and birth year for clean fleece weight of the Elsenburg SAMM resource flock from 1983 to 2018. The vertical lines about means denote standard errors.

The coefficient of variation of fibre diameter showed significant differences for birth type and age of dam although these differences were relatively small (Table 2.4). Birth type was the only significant (P <0.05) fixed effect for fibre diameter, with singles producing slightly finer wool than twins and triplets. Although the effects were small, sex and birth type significantly affected fibre diameter in the study of Cloete *et al*. (1998a). Brash *et al*. (1994a) reported significant differences for sex and birth type in Corriedale sheep. Brown *et al*. (1966) also found that birth type significantly affected fibre diameter. It was observed that with twins and triplets the number of follicles per skin area was reduced during late gestation, while under-nutrition can also prevent the development of some follicles, therefore producing coarser wool than singles (Khan *et al*., 2012). Sex had a significant fixed effect on fibre diameter for Merinos, Dohne Merinos and SAMMs in the study of Cloete *et al*. (2001b), whereas birth type did not influence fibre diameter during that study. The effect of age of dam on fibre diameter was also not significant in the study by Wuliji *et al*. (2011) on yearling Romney sheep or for Merinos and SAMMs in the paper by Cloete *et al*. (2001b).

2.3.3 Log likelihood values

Table 2.5 provides the log likelihood ratios for random effects models fitted to early growth traits and lamb survival. The random effects fitted to early growth traits indicated that model 6 provided the best fit for birth weight and weaning weight, whereas the best model for lamb

survival was model 5 (Table 2.5). The best random model for birth weight corresponded well with the study of Cloete *et al*. (1998a) for Dohne Merinos. In contrast, the latter study only fitted the direct additive effect and the dam permanent environmental effect for weaning weight. A study of Elsenburg Dormers by Van Wyk *et al*. (2003) included the direct additive, maternal additive, the permanent environment (PE) of the dam, the temporary environment due to litter, as well as the genetic correlation between animal effects. The best model for weaning weight in the latter study included the direct additive, maternal additive, dam PE and litter effects in the latter study, while the best model for lamb survival only included direct additive and litter effects. Evidently, these models did not correspond well with those fitted in the current study. Cloete *et al*. (2001a) additionally included random paddock effect and between bloodline variances for birth weight, weaning weight and lamb survival, whereas the current study also included the litter effect in the models for these traits. The models for birth weight and weaning weight corresponded with those fitted in the current study. The model for lamb survival only included direct and maternal additive effects in the latter study (Cloete *et al.*, 2001a), which did not compare well with the current study because the current study included the dam PE effect and not the maternal additive effect. Models for weaning weight of Dohne Merinos and SAMMs included direct and maternal additive and the genetic correlation between animal effects in the study of Cloete *et al*. (2001b), whereas the model for weaning weight of Merinos only included direct and maternal additive effects.

Table 2.5 Log likelihood ratios for random effects models fitted to early growth traits and lamb survival of the Elsenburg SAMM flock with the best fitted model in bold.

Model	(Co)variance components	BW	WW	LS
0	Fixed effects	-2542.35	-8189.72	4754.55
1	h^2	-2102.36	-8125.45	4790.89
2	$h^2 + c^2$	-1732.10	-8067.62	4836.23
3	$h^2 + m^2$	-1689.69	-8066.87	4819.26
4	$h^2 + m^2 + c^2$	-1661.50	-8057.50	4837.49
5	$h^2 + c^2 + l^2$	-1548.83	-8021.49	***4884.97***
6	$h^2 + m^2 + c^2 + l^2$	***-1478.80***	***-8010.57***	4886.37
7	$h^2 + m^2 + r_{am}$	-1688.24	-8066.51	4820.09
8	$h^2 + m^2 + c^2 + r_{am}$	-1658.94	-8057.38	4839.59
9	$h^2 + m^2 + c^2 + l^2 + r_{am}$	-1477.05	-8010.57	4887.44

h^2 = direct additive; c^2 = permanent environmental due to dam; m^2 = maternal additive; l^2 = litter; r_{am} = genetic correlation between animal effects; BW = birth weight; WW = weaning weight; LS = lamb survival

Table 2.6 illustrates the log likelihood ratios for random effects models fitted to yearling weight and wool traits. The best model for clean yield, staple length, coefficient of variation of fibre diameter and fibre diameter only included the direct additive effect, whereas the models for yearling weight and clean fleece weight also included respectively the direct additive and the dam PE effect (Table 2.6). Only the direct additive effect was included in the most suitable

models for the yearling traits such as yearling weight, clean yield, clean fleece weight, staple length and fibre diameter in the study by Cloete *et al*. (1998a). These results only corresponded with models for clean yield, staple length and fibre diameter of the current study. The best models for yearling weight, clean yield, clean fleece weight and fibre diameter in Table 2.6 for SAMMs corresponded well with those of Cloete *et al*. (2004). Matebesi-Ranthimo *et al*. (2017) only included the direct additive random effect of animal in analyses on clean yield, staple length and coefficient of variation of fibre diameter whereas models for clean fleece weight and fibre diameter included the direct and maternal additive effects as random. The models chosen for clean yield, staple length and coefficient of variation of fibre diameter in the latter study corresponded well with the current study. The best model for yearling weight of Dohne Merinos and SAMMs included direct and maternal additive effects, whereas the model for Merinos only included the direct additive effect in the study of Cloete *et al*. (2001b). The model for fibre diameter of Merinos, Dohne Merinos and SAMMs in the latter study only included the direct additive effect.

Table 2.6 Log likelihood ratios for random effects models fitted to yearling weight and wool traits of the Elsenburg SAMM flock with the best fitted model in bold.

Model	(Co)variance components	YW	CY	CFW	SL	CVFD	FD
0	Fixed effects	-6540.46	-6708.44	1473.76	-6407.23	-1367.32	-2219.92
1	h^2	-6476.46	***-6502.22***	1604.06	***-6333.72***	***-1309.45***	***-1980.27***
2	$h^2 + c^2$	***-6463.61***	-6501.67	***1610.28***	-6333.08	-1309.33	-1980.27
3	$h^2 + m^2$	-6465.46	-6502.07	1607.76	-6333.69	-1309.17	-1980.12
4	$h^2 + m^2 + c^2$	-6462.10	-6501.67	1610.50	-6333.08	-1309.17	-1980.12
5	$h^2 + m^2 + r_{am}$	-6465.38	-6499.97	1608.45	-6333.53	-1309.16	-1979.99
6	$h^2 + m^2 + c^2 + r_{am}$	-6461.90	-6499.92	1611.09	-6332.39	-1309.16	-1979.99

h^2: direct additive; c^2: permanent environmental due to dam; m^2: maternal additive; r_{am}: genetic correlation between animal effects; YW: yearling weight; CY: clean yield; CFW: clean fleece weight; SL: staple length; CVFD: coefficient of variation of fibre diameter; FD: fibre diameter

2.3.4 Single- and multi-trait heritability estimates

Tables 2.7 and 2.10 provide the variance components and ratios for early growth, yearling weight and wool traits and lamb survival. Birth weight and weaning weight had low single-trait heritability estimates of 0.07 and 0.03 respectively whereas yearling weight had a moderate heritability of 0.24 (Table 2.7; Table 2.10). The total heritability derived from the single-trait analyses amounted to 0.15 for birth weight and 0.06 for weaning weight which were lower than the total heritability estimates from Van Wyk *et* al. (1993) for Dormers. In a three-trait analysis these heritability estimates amounted to 0.08 for birth weight, 0.05 for weaning weight and 0.20 for yearling weight (Table 2.8). The total phenotypic variances in single-trait analyses increased from birth weight to yearling weight, amounting to 0.55 for birth weight, 13.9 for weaning weight

and 24.3 for yearling weight (Table 2.7; Table 2.10). These results corresponded well with those found in the three-trait analysis, although the total phenotypic variances for weaning weight and yearling weight in the three-trait analyses were higher than those in the single-trait analyses (Table 2.8). Estimates reported in the literature, based mostly on wool and dual-purpose breeds, reported heritability ranges of 0.04 to 0.39 for birth weight, 0.06 to 0.35 for weaning weight and 0.23 to 0.58 for yearling weight (Tables 2.9 and 2.12). Birth weight and yearling weight from the single-trait estimates were within these ranges, whereas the heritability of weaning weight was just below the reported range. The three-trait heritability estimate for birth weight were within the range derived from literature but estimates for weaning and yearling weight were lower than these ranges. The heritability of yearling weight in the six-trait analysis, however, corresponded with this range.

Table 2.7 Variance components and ratios (±SE) for early growth traits and lamb survival in the Elsenburg SAMM flock.

Trait	Birth weight	Weaning weight	Lamb survival*	Lamb survival**
(Co)variance components				
σ^2_a	0.04	0.67	0.001	0.003
σ^2_m	0.08	1.21	-	-
σ^2_c	0.04	0.74	0.008	0.007
σ^2_l	0.12	3.98	0.02	0.02
σ^2_p	0.55	13.9	0.17	0.18
Variance ratios				
h^2	0.07 ± 0.02	0.03 ± 0.01	0.008 ± 0.007	0.02 ± 0.009
m^2	0.15 ± 0.02	0.06 ± 0.02	-	-
c^2	0.07 ± 0.01	0.04 ± 0.01	0.05 ± 0.008	0.04 ± 0.008
l^2	0.21 ± 0.01	0.19 ± 0.02	0.12 ± 0.014	0.13 ± 0.01

σ^2_p: total phenotypic variance; σ^2_a: direct additive variance; σ^2_m: maternal additive variance; σ_{am}: Covariance; σ^2_c: permanent environmental variance; h^2: direct heritability; m^2: maternal heritability; c^2: maternal permanent environment; l^2: litter; *: birth weight included; **: birth weight excluded

The heritability of lamb survival was 0.008 when birth weight was modelled and increased to 0.02 when birth weight was not included in the analyses (Table 2.7). The heritability of lamb survival ranged from 0.03 to 0.09 in previous studies on woolled breeds. The estimate from the current study was thus below this range (Table 2.9). Single-trait maternal heritability estimates decreased from birth weight to weaning weight, at 0.15 and 0.06 respectively (Table 2.7). The latter result for birth weight was similar to the maternal heritability for birth weight (0.13) in the three-trait analyses whereas the corresponding maternal heritability for weaning weight amounted to 0.01 (Table 2.7; 2.8). Corresponding values for birth weight and weaning weight from previous studies ranged from 0.10 to 0.22 for birth weight and from 0.08 to 0.30 for weaning weight (Table 2.9). The present value for birth weight was consistent with this range, but below the values in Table 2.9 for weaning weight.

Table 2.8 Three-trait (co)variance components and ratios (±SE) for birth weight, weaning weight and yearling weight (weight traits) of the Elsenburg SAMM flock.

Trait	Birth weight	Weaning weight	Yearling weight
h^2 on diagonal, r_g below diagonal			
Birth weight	**0.08 ± 0.02**	-	-
Weaning weight	0.06 ± 0.17	**0.05 ± 0.01**	-
Yearling weight	0.04 ± 0.15	0.81 ± 0.10	**0.20 ± 0.03**
m^2 on diagonal, r_m below diagonal			
Birth weight	**0.13 ± 0.02**	-	-
Weaning weight	0.50 ± 0.19	**0.01 ± 0.008**	-
σ^2_p on diagonal, r_e above and r_p below diagonal			
Birth weight	**0.36 ± 0.01**	0.36 ± 0.02	0.36 ± 0.02
Weaning weight	0.29 ± 0.01	**18.7 ± 0.44**	0.70 ± 0.01
Yearling weight	0.27 ± 0.02	0.67 ± 0.01	**27.3 ± 0.75**
c^2 on diagonal, r_c below diagonal			
Birth weight	**0.09 ± 0.01**	-	-
Weaning weight	0.54 ± 0.10	**0.07 ± 0.01**	-
Yearling weight	0.69 ± 0.11	0.97 ± 0.07	**0.09 ± 0.02**
l^2	**0.22 ± 0.01**	**0.10 ± 0.01**	-

σ^2_p: total phenotypic variance component; r_p: phenotypic correlation; h^2: direct additive variance ratio; r_g: genetic correlation; m^2: maternal additive variance ratio; r_m: maternal correlation; c^2: dam permanent environmental variance ratio; r_c: dam permanent environmental correlation; l^2: litter variance ratio

Dam PE variance ratios derived from single-trait analyses amounted to 0.07 for birth weight, 0.04 for weaning weight, 0.05 for lamb survival modelled with birth weight and 0.04 for lamb survival modelled without birth weight (Table 2.7) and 0.08 for yearling weight (Table 2.10). The three-trait estimates for weight traits were slightly higher amounting to 0.09 for birth weight, 0.07 for weaning weight and 0.09 for yearling weight (Table 2.8). Estimates from previous woolled breeds in the literature ranged from 0.08 to 0.37 for birth weight, 0.02 to 0.21 for weaning weight and 0.09 to 0.10 for yearling weight (Table 2.9; Table 2.12). The present single- and multi-trait estimates mostly corresponded with the lower boundary of the ranges from the literature. The dam permanent environmental variance ratio for lamb survival corresponded very well with values reported by Cloete *et al*. (2001b) for Merinos (Table 2.9). The litter variance ratio from the single-trait analyses contributed most to the total phenotypic variance for early growth traits and lamb survival, amounting to 0.21 for birth weight, 0.19 for weaning weight and 0.12 for lamb survival (Table 2.7). Values presented by Muller *et al.* (2020) corresponded well with the current study and found that the litter variance ratios from the single-trait analyses for Dormers amounted to 0.28 for birth weight, 0.24 for weaning weight and 0.12 to 0.13 for lamb survival. The litter variance ratio for birth weight and weaning weight in the three-trait analyses was similar for birth weight at 0.22 but lower for weaning weight at 0.10. The study of Muller *et al*. (2020) reported litter variance ratios from a three-trait analyses to be 0.27 for birth weight and 0.18 for weaning weight, which were higher compared to the present study.

Table 2.9 Summary of published variance ratios for birth weight, weaning weight and lamb survival.

Breed	h^2	m^2	c^2	Reference
Birth weight				
Hampshire	0.39	0.22	0.37	Tosh & Kemp, 1994
Merino	0.18	0.15	0.08	Cloete *et al*., 2001b
Merino	0.23	0.14	0.12	Mortimer & Atkins, 1995
Afrino	0.33	0.17	-	Snyman *et al*., 1995a
Dohne Merino	0.04	0.10	0.17	Cloete *et al*., 1998a
Wool	0.21	-	-	Safari *et al*., 2005
Wool	0.21	0.21	0.10	Safari *et al*., 2005
Weaning weight				
Dohne Merino	0.06	-	0.21	Cloete *et al*., 1998a
Dohne Merino	0.21	0.30	-	Cloete *et al*., 2001b
Afrino	0.33	0.17	-	Snyman *et al*., 1995a
Merino (Katanning)	0.30	0.08	0.07	Cloete *et al*., 2001a
Merino	0.19 - 0.25	0.14 - 0.23	0.02	Hickson *et al*., 1995
Merino	0.27	0.11	0.07	Mortimer & Atkins, 1995
Merino	0.14	0.11	0.05	Snyman *et al*., 1996
Merino	0.24	0.23	-	Swan & Hickson, 1994
Merino	0.18	0.15	-	Cloete *et al*., 2001b
SAMM	0.13 - 0.35	0.17	0.07	Neser *et al*., 1998
SAMM	0.14 - 0.19	0.09 - 0.20	0.10	Neser *et al*., 2000
SAMM	0.32	0.15	0.07	Gray *et al*., 1999
SAMM	0.32	0.24	-	Cloete *et al*., 2001b
Wool	0.23	-	-	Safari *et al*., 2005
Wool	0.21	0.16	0.06	Safari *et al*., 2005
Lamb survival				
Merino	0.09	-	0.04	Cloete *et al*., 2001b
All breeds	0.03	-	-	Safari *et al*., 2005
All breeds	0.03	0.05	-	Safari *et al*., 2005

CV: coefficient of variation; *: Birth weight included; **: Birth weight excluded

Wool traits were highly heritable in single-trait analyses, estimates ranging from 0.34 for staple length to 0.68 for fibre diameter (Table 2.10). The corresponding six-trait analyses with yearling weight recorded heritability estimates for the wool traits ranging from 0.36 for staple length to 0.66 for fibre diameter (Table 2.11). Estimates from the literature on mostly wool- and dual-purpose breeds ranged from 0.41 to 0.66 for clean yield, 0.28 to 0.68 for clean fleece weight, 0.33 to 0.46 for staple length, 0.47 to 0.60 for coefficient of variation of fibre diameter and 0.43 to 0.75 for fibre diameter (Table 2.12). The single- and multi-trait heritability estimates in the present study thus corresponded very well with these literature values. Clean fleece weight recorded a dam PE variance ratio of 0.05, which agreed with the value of 0.06 derived earlier by Cloete *et al*. (2004) for the same SAMM flock. (Table 2.10; Table 2.12). The single-trait additive and phenotypic variance components presented in Table 2.10 corresponded well with those presented in Table 2.12 for the six-trait analyses. These results also corresponded

well with those reported by Cloete *et al*. (2001b) for Merinos, Dohne Merinos and SAMMs and by Cloete *et al*. (2002) for Western Australian Merino sheep.

Table 2.10 Variance components and ratios (±SE) for yearling weight and wool traits in the Elsenburg SAMM flock.

Trait	(Co)variance components			Variance ratios	
	σ^2_a	σ^2_c	σ^2_p	h^2	c^2
Yearling weight	5.92	2.02	24.3	0.24 ± 0.04	0.08 ± 0.02
Clean yield	13.3	-	22.8	0.58 ± 0.04	-
Clean fleece weight	0.05	0.007	0.14	0.37 ± 0.04	0.05 ± 0.02
Staple length	57.6	-	169.3	0.34 ± 0.05	-
CV of fibre diameter	2.08	-	3.77	0.55 ± 0.07	-
Fibre diameter	1.47	-	2.17	0.68 ± 0.04	-

σ^2_p = Total phenotypic variance; σ^2_a = Direct additive variance; σ^2_c = Permanent environmental variance; h^2 = Direct heritability; c^2 = Maternal permanent environment; CV = coefficient of variation

Table 2.11 Six-trait variance components (in bold) as well as (co)variance ratios (±SE) for the yearling weight and yearling wool traits of the Elsenburg SAMM flock.

Trait	Correlated trait	Heritability (bold) or genetic correlation (r_g)	Environmental variance (bold) or correlation (r_e)	Phenotypic variance (bold) or correlation (r_p)
Yearling weight	**Yearling weight**	**0.26 ± 0.04**	**16.5 ± 0.78**	**22.8 ± 0.80**
	Clean yield	-0.01 ± 0.09	-0.00 ± 0.04	-0.01 ± 0.02
	Clean fleece weight	0.17 ± 0.10	0.45 ± 0.03*	0.34 ± 0.02*
	Staple length	-0.18 ± 0.07*	0.07 ± 0.04	0.04 ± 0.03
	CV of fibre diameter	-0.18 ± 0.14	-0.19 ± 0.06*	-0.18 ± 0.04*
	Fibre diameter	0.21 ± 0.09*	0.24 ± 0.05*	0.21 ± 0.02*
Clean yield	**Clean yield**	**0.58 ± 0.04**	**9.77 ± 0.65**	**23.1 ± 0.79**
	Clean fleece weight	0.39 ± 0.07*	0.38 ± 0.04*	0.37 ± 0.02*
	Staple length	0.27 ± 0.08*	0.22 ± 0.05*	0.23 ± 0.03*
	CV of fibre diameter	0.11 ± 0.10	-0.15 ± 0.07*	-0.006 ± 0.04
	Fibre diameter	0.32 ± 0.06*	-0.18 ± 0.06*	0.13 ± 0.03*
Clean fleece weight	**Clean fleece weight**	**0.38 ± 0.04**	**0.09 ± 0.005**	**0.14 ± 0.005**
	Staple length	0.52 ± 0.09*	0.16 ± 0.04*	0.29 ± 0.02*
	CV of fibre diameter	0.03 ± 0.13	-0.21 ± 0.07*	-0.10 ± 0.04*
	Fibre diameter	0.39 ± 0.07*	0.21 ± 0.05*	0.29 ± 0.02*
Staple length	**Staple length**	**0.36 ± 0.05**	**111.7 ± 0.04**	**173.6 ± 6.62**
	CV of fibre diameter	-0.32 ± 0.12*	-0.006 ± 0.07	-0.15 ± 0.04*
	Fibre diameter	0.04 ± 0.09	0.01 ± 0.06	0.02 ± 0.03
CV of fibre diameter	**CV of fibre diameter**	**0.54 ± 0.06**	**1.71 ± 0.19**	**3.74 ± 0.21**
	Fibre diameter	-0.06 ± 0.12	-0.14 ± 0.12	-0.09 ± 0.04*
Fibre diameter	**Fibre diameter**	**0.66 ± 0.04**	**0.75 ± 0.07**	**2.20 ± 0.08**

* - Significant correlation; SE - Standard error; CV - Coefficient of variation

Table 2.12 Summary of published variance ratios for yearling live weight and yearling wool traits in the literature.

Breed	h^2	m^2 (c^2)	Reference
Yearling weight			
Dohne Merino	0.24	-	Cloete *et al*., 1998a
Dohne Merino	0.33	0.13	Cloete *et al*., 2001b
Afrino	0.58	0.05	Snyman *et al*., 1995a
Merino	0.45	-	Brash *et al*., 1997
Merino	0.33 - 0.35	0.12	Hickson *et al*., 1995
Merino	0.33	0.08	Mortimer & Atkins, 1994
Merino	0.46	-	Ponzoni *et al*., 1995
Merino	0.48	-	Purvis & Swan, 1997
Merino	0.28	0.12 - 0.14	Swan & Hickson, 1994
Merino	0.24	0.15	Vaez Torshizi *et al*., 1995
Merino	0.30	-	Cloete *et al*., 2001b
SAMM	0.23	(0.09)	Cloete *et al*., 2004
SAMM	0.45	0.12	Cloete *et al*., 2001b
Wool	0.41	-	Safari *et al*., 2005
Wool	0.42	0.04 (0.10)	Safari *et al*., 2005
Clean yield			
Dohne Merino	0.66	-	Cloete *et al*., 1998a
Merino	0.41	-	Brash *et al*., 1997
Merino	0.57	-	Ponzoni *et al*., 1995
Merino	0.55 - 0.60	-	Swan *et al*., 1995
Merino	0.60	-	Matebesi-Ranthimo *et al*., 2017
SAMM	0.59	-	Cloete *et al*., 2004
Wool	0.56	-	Safari *et al*., 2005
Clean fleece weight			
Dohne Merino	0.35	-	Cloete *et al*., 1998a
Dohne Merino	0.28	0.12	Cloete *et al*., 2001b
Afrino	0.62	-	Snyman *et al*., 1995a
Merino	0.39	-	Brash *et al*., 1997
Merino	0.28 - 0.34	0.06 - 0.14	Hickson *et al*., 1995
Merino	0.59	-	Ponzoni *et al*., 1995
Merino	0.29	-	Purvis & Swan, 1997
Merino	0.28 - 0.31	-	Swan *et al*., 1995
Merino	0.31	0.09	Matebesi-Ranthimo *et al*., 2017
Merino	0.28	0.12	Cloete *et al*., 2001b
SAMM	0.39	(0.06)	Cloete *et al*., 2004
SAMM	0.68	-	Cloete *et al*., 2001b
Wool	0.37	-	Safari *et al*., 2005
Wool	0.28	0.06 (0.21)	Safari *et al*., 2005
Staple length			
Merino	0.33	-	Matebesi-Ranthimo *et al*., 2017
Wool	0.46	-	Safari *et al*., 2005

Coefficient of variation of fibre diameter			
Merino	0.54	-	Brash *et al*., 1997
Merino	0.59	-	Ponzoni *et al*., 1995
Merino	0.55	-	Purvis & Swan, 1997
Merino	0.47	-	Swan *et al*., 1995
Merino	0.60	-	Matebesi-Ranthimo *et al*., 2017
All breeds	0.52	-	Safari *et al*., 2005
Fibre diameter			
Dohne Merino	0.43	-	Cloete *et al*., 1998a
Dohne Merino	0.61	-	Cloete *et al*., 2001b
Afrino	0.73	-	Snyman *et al*., 1995a
Merino	0.58	-	Brash *et al*., 1997
Merino	0.45	-	Ponzoni *et al*., 1995
Merino	0.60	-	Purvis & Swan, 1997
Merino	0.44 - 0.45	0.01	Swan & Hickson, 1994
Merino	0.58 - 0.67	-	Swan *et al*., 1995
Merino	0.54	-	Vaez Torshizi *et al*., 1995
Merino	0.54	0.03	Matebesi-Ranthimo *et al*., 2017
Merino	0.59	-	Cloete *et al*., 2001b
SAMM	0.67	-	Cloete *et al*., 2004
SAMM	0.75	-	Cloete *et al*., 2001b
All breeds	0.59	-	Safari *et al*., 2005

CV – coefficient of variation

2.3.5 Genetic correlations among traits

The correlations among the weight traits that resulted from the three-trait analyses were all significant except for the direct genetic correlations of birth weight with weaning weight and yearling weight (Table 2.8). The genetic correlation of weaning weight with yearling weight was high at 0.81, while the maternal genetic correlation of birth weight with weaning weight amounted to 0.50. The phenotypic and environmental correlations of birth weight with weaning weight and yearling weight were moderate and below 0.40. The phenotypic and environmental correlations of weaning weight with yearling weight were high and at respectively 0.67 and 0.70. The dam permanent environmental correlations of birth weight with weaning weight and with yearling weight were high at respectively 0.54 and 0.69. The dam permanent environmental correlation of weaning weight with yearling weight recorded an extremely high value of 0.97 that did not differ from unity.

From the six-trait analyses the genetic correlations of yearling weight with the wool traits were low, ranging from -0.18 for staple length and coefficient of variation of fibre diameter to 0.21 for fibre diameter (Table 2.11). Only the genetic correlations with staple length and fibre diameter reached significance (i.e. a level larger than two times the corresponding standard error) and only the latter exceeded 0.20. Only one comparable estimate was available for the

genetic correlation of yearling weight with wool traits (Safari *et al*., 2005; Table 2.13). In Safari *et al*. (2005), the genetic correlations of yearling weight with clean yield (0.00), clean fleece weight (0.21), staple length (0.01) and coefficient of variation of fibre diameter (-0.08) were larger than the corresponding values from the current study. In contrast, the genetic correlation with fibre diameter was smaller, at 0.15 (Table 2.13). Phenotypic correlations of yearling weight with the wool traits ranged from -0.17 for coefficient of variation of fibre diameter to 0.34 for clean fleece weight and only these two correlations together with the correlation of yearling weight with fibre diameter (0.20) reached significance (Table 2.11). Literature estimates from Safari *et al*. (2005) mostly corresponded well with phenotypic correlations of post weaning weight with clean yield (0.02), clean fleece weight (0.35), staple length (0.10) and coefficient of variation of fibre diameter (-0.06) having larger values compared to the present results. The phenotypic correlation of yearling weight with fibre diameter has a smaller value of 0.13 than the current study (Safari *et al*., 2005; Table 2.13).

From Table 2.11 it was evident that clean yield had low to moderate genetic correlations with the other wool traits ranging from 0.11 for coefficient of variation of fibre diameter to 0.39 for clean fleece weight. Only the genetic correlations with clean fleece weight, staple length (0.27) and fibre diameter (0.32) were significant. The genetic correlations of clean yield with clean fleece weight and staple length were within range reported in the literature that ranged from 0.28 to 0.66 (n = 8) and 0.19 to 0.34 (n = 5) respectively (Table 2.13). The positive genetic correlation of clean yield with coefficient of variation of fibre diameter (0.11) in the current study was opposite in sign compared to previous literature in (-0.26 to -0.07; n = 6). The genetic correlation of clean yield with fibre diameter (0.32) in the current study fell outside of the range and was higher than the presented literature ranging from -0.02 to 0.09 (n = 8; Table 2.13). The phenotypic correlations of clean yield with other wool traits amounted to 0.37 for clean fleece weight, 0.23 for staple length, -0.01 for coefficient of variation of fibre diameter and 0.13 for fibre diameter (Table 2.11). Phenotypic correlations with clean fleece weight, staple length and fibre diameter were significant. The phenotypic correlation of clean yield with clean fleece weight (0.37) was within the range of 0.24 to 0.54 from the literature (Table 2.13). The phenotypic correlations of clean yield with staple length, coefficient of variation of fibre diameter and fibre diameter were slightly higher than the respective literature ranges of 0.12 to 0.21, -0.18 to -0.09 and -0.12 to 0.02.

Table 2.13 Summary of published genetic (r_g) and phenotypic (r_p) correlations among yearling weight and the yearling wool traits.

Correlated traits	r_g	r_p	Breed	References
Yearling weight x				
Clean yield	0.00	0.02	All breeds	Safari *et al*., 2005
Clean fleece weight	0.21	0.35	All breeds	Safari *et al*., 2005
Staple length	0.01	0.10	All breeds	Safari *et al*., 2005
CV of fibre diameter	-0.08	-0.06	All breeds	Safari *et al*., 2005
Fibre diameter	0.15	0.13	All breeds	Safari *et al*., 2005
Clean yield x				
Clean fleece weight	0.38	0.37	All breeds	Safari *et al*., 2005
Clean fleece weight	0.28	0.35	Merino	Safari *et al*., 2007
Clean fleece weight	0.38	0.24	Merino	Cloete *et al*., 1998b
Clean fleece weight	0.66	0.52	Merino	Hill, 2001
Clean fleece weight	0.49	0.31	Merino	Hill, 2001
Clean fleece weight	0.31	0.54	Merino	Wuliji *et al*., 2001
Clean fleece weight	0.37	-	Merino	Cloete *et al*., 2002
Clean fleece weight	0.39	0.28	Merino	Sherlock *et al*., 2003
Staple length	0.25	0.19	All breeds	Safari *et al*., 2005
Staple length	0.34	0.16	Merino	Cloete *et al*., 1998b
Staple length	0.30	0.21	Merino	Hill, 2001
Staple length	0.23	0.21	Merino	Hill, 2001
Staple length	0.19	0.12	Merino	Wuliji *et al*., 2001
CV of fibre diameter	-0.08	-0.13	All breeds	Safari *et al*., 2005
CV of fibre diameter	-0.14	-0.10	Merino	Safari *et al*., 2007
CV of fibre diameter	-0.09	-	Merino	Cloete *et al*., 2002
CV of fibre diameter	-0.26	-0.18	Merino	Wuliji *et al*., 2001
CV of fibre diameter	-0.16	-0.09	Merino	Hill, 2001
CV of fibre diameter	-0.07	-0.09	Merino	Hill, 2001
Fibre diameter	0.04	0.01	All breeds	Safari *et al*., 2005
Fibre diameter	0.06	-0.00	Merino	Safari *et al*., 2007
Fibre diameter	-0.01	-0.12	Merino	Cloete *et al*., 1998b
Fibre diameter	0.08	0.02	Merino	Hill, 2001
Fibre diameter	0.09	-0.02	Merino	Hill, 2001
Fibre diameter	0.09	0.00	Merino	Wuliji *et al*., 2001
Fibre diameter	-0.01	-	Merino	Cloete *et al*., 2002
Fibre diameter	-0.02	-0.08	Merino	Sherlock *et al*., 2003
Clean fleece weight x				
Staple length	0.36	0.33	All breeds	Safari *et al*., 2005
Staple length	0.24	0.21	Merino	Cloete *et al*., 1998b
Staple length	0.28	0.33	Merino	Hill, 2001
Staple length	0.43	0.36	Merino	Hill, 2001
Staple length	0.21	0.30	Merino	Wuliji *et al*., 2001

CV of fibre diameter	0.19	-0.04	All breeds	Safari *et al*., 2005
CV of fibre diameter	0.01	0.01	Merino	Safari *et al*., 2007
CV of fibre diameter	0.09	-0.05	Merino	Hill, 2001
CV of fibre diameter	-0.08	-0.01	Merino	Hill, 2001
CV of fibre diameter	-0.05	-0.03	Merino	Wuliji *et al*., 2001
CV of fibre diameter	0.07	-	Merino	Cloete *et al*., 2002
CV of fibre diameter	-0.02	-0.11	Merino	Lee *et al*., 2002
Fibre diameter	0.19	0.19	All breeds	Safari *et al*., 2005
Fibre diameter	0.29	0.24	Merino	Safari *et al*., 2007
Fibre diameter	0.26	0.20	Merino	Cloete *et al*., 1998b
Fibre diameter	0.32	0.12	Merino	Lee *et al*., 2002
Fibre diameter	0.15	0.21	Merino	Wuliji *et al*., 2001
Fibre diameter	0.11	0.16	Merino	Hill, 2001
Fibre diameter	0.38	0.35	Merino	Hill, 2001
Fibre diameter	0.45	0.58	Merino	Fogarty *et al*., 2003
Fibre diameter	0.38	0.24	Merino	Sherlock *et al*., 2003
Fibre diameter	0.31	-	Merino	Cloete *et al*., 2002
Staple length x				
CV of fibre diameter	-0.06	-0.12	All breeds	Safari *et al*., 2005
CV of fibre diameter	-0.20	-0.11	Merino	Hill, 2001
CV of fibre diameter	-0.21	-0.13	Merino	Hill, 2001
CV of fibre diameter	-0.16	-0.10	Merino	Wuliji *et al*., 2001
CV of fibre diameter	-0.04	-0.12	Merino	Brown *et al*., 2002
Fibre diameter	0.19	0.19	All breeds	Safari *et al*., 2005
Fibre diameter	0.34	0.13	Merino	Cloete *et al*., 1998b
Fibre diameter	0.22	0.26	Merino	Hill, 2001
Fibre diameter	0.30	0.26	Merino	Hill, 2001
Fibre diameter	0.00	0.07	Merino	Wuliji *et al*., 2001
Fibre diameter	0.24	0.29	Merino	Brown *et al*., 2002
CV of fibre diameter x				
Fibre diameter	-0.10	-0.09	All breeds	Safari *et al*., 2005
Fibre diameter	-0.16	-0.10	Merino	Safari *et al*., 2007
Fibre diameter	-0.05	-0.09	Merino	Hill, 2001
Fibre diameter	-0.24	-0.16	Merino	Hill, 2001
Fibre diameter	-0.03	-0.05	Merino	Wuliji *et al*., 2001
Fibre diameter	-0.23	-0.20	Merino	Brown *et al*., 2002
Fibre diameter	-0.10	-	Merino	Cloete *et al*., 2002
Fibre diameter	-0.10	-0.02	Merino	Lee *et al*., 2002

CV: coefficient of variation

Clean fleece weight had relatively high and significant genetic correlations with staple length (0.52) and fibre diameter (0.39) whereas the correlation with coefficient of variation of fibre diameter was small and not significant at 0.03 (Table 2.11). The genetic correlation estimates for clean fleece weight with coefficient of variation of fibre diameter and fibre diameter were within the derived estimate ranges of -0.08 to 0.19 (n = 7) and 0.11 to 0.45 (n = 10),

respectively (Table 2.13). The genetic correlation of clean fleece weight with staple length was somewhat higher than the range derived from previous literature of 0.21 to 0.43 (n = 5). Clean fleece weight was significantly correlated with all the other wool traits on the phenotypic level. The phenotypic correlations of clean fleece weight with staple length (0.29), fibre diameter (0.29) and coefficient of variation of fibre diameter (-0.10) were all within the corresponding ranges of respectively 0.21 to 0.36 (n = 5), 0.12 to 0.58 (n = 9) and -0.11 to 0.01 (n = 6) in literature cited (Table 2.11 and Table 2.13).

Staple length was significantly correlated with coefficient of variation of fibre diameter on a genetic and phenotypic level but not with fibre diameter (Table 2.11). The genetic correlation of staple length with coefficient of variation of fibre diameter (-0.32) fell outside the derived range of literature values of -0.21 to -0.04 (n = 5; Table 2.13). The genetic correlation of staple length with fibre diameter was on the lower end of the derived range of 0.00 to 0.34 (n = 6). The phenotypic correlation estimates for staple length with both coefficient of variation of fibre diameter and fibre diameter (-0.15 and 0.02 respectively) fell just outside of their respective ranges of -0.13 to -0.10 (n = 5) and 0.07 to 0.29 (n = 6) reported previously in literature.

At -0.06, the coefficient of variation of fibre diameter did not significantly correlate with fibre diameter on a genetic level (Table 2.11). The latter estimate was within the derived range of estimates from previous literature of -0.24 to -0.03 (n = 8; Table 2.13). However, the correlation of coefficient of variation of fibre diameter with fibre diameter on a phenotypic level was significant with a value of -0.09 (Table 2.11). This estimate fell well within the derived literature range of -0.20 to -0.02 derived from the literature (n = 7; Table 2.13).

2.3.6 Genetic trends

Genetic trends for the early weight traits of SAMMs were calculated from 1955 to 2019. Genetic change in all traits was significant and the change detected was slow and never surpassed 0.1% of the overall phenotypic mean for any trait (Table 2.14). Weaning weight showed a 0.08% annual increase in direct breeding values, whereas the maternal breeding values increased at a slower rate of 0.02% p.a. of the phenotypic mean. Table 2.14 and Figure 2.3 demonstrate the faster direct genetic change in weaning weight. The direct breeding values for yearling weight were included in the analyses for the genetic trends of the early weight traits and also when the genetic trends for the yearling traits were calculated over a shorter time span. The genetic change estimated from both approaches was quite similar at respectively 0.09% and 0.08% p.a. (Table 2.14).

Table 2.14 The intercept and slope of regression equations, depicting genetic trends in the units of measurement, as well as expressed as a percentage of the overall phenotypic mean of the respective traits, as indication of change in the genetic merit, as expressed relative to the overall mean.

Trait	Intercept ± SE	Coefficient (slope) ± SE	Genetic merit (%)
BW_{direct} (kg)	-0.00747 ± 0.00414	-0.0001 ± 0.0000491	-0.00235
$BW_{maternal}$ (kg)	-0.225 ± 0.00646	0.0033 ± 0.0000766	0.0776
WW_{direct} (kg)	-1.43 ± 0.0206	0.0213 ± 0.000244	0.078
$WW_{maternal}$(kg)	-0.378 ± 0.00825	0.00485 ± 0.0000979	0.0178
YW_{direct} (kg)	-3.19 ± 0.047	0.0437 ± 0.000558	0.0879
YW* (kg)	-3.32 ± 0.0502	0.038 ± 0.000596	0.076
CY (%)	-0.644 ± 0.0798	0.00116 ± 0.000946	0.00174
CFW (kg)	-0.149 ± 0.00504	0.00135 ± 0.0000598	0.0652
SL (mm)	-3.00 ± 0.143	0.0190 ± 0.0017	0.0202
CVFD (%)	0.487 ± 0.0209	-0.00403 ± 0.000248	-0.0225
FD (µm)	-0.334 ± 0.0288	0.00343 ± 0.000341	0.015

BW: birth weight (kg); WW: weaning weight (kg); YW: yearling weight (kg); CFW: clean fleece weight (kg); FD: fibre diameter (µm); CVFD: coefficient of variation of fibre diameter (%); SD: standard deviation; CY: clean yield (%); SL: staple length (mm); direct = direct genetic trend; maternal = maternal genetic trend
*: yearling weight calculated using yearling traits

The genetic trends for wool traits were derived over a shorter period as records were not always available. It was evident that no direct selection pressure had been placed on any of the wool traits as these genetic changes were small and ranged from increases of 0.002% p.a. for clean yield to 0.07% p.a. for clean fleece weight. It was assumed that the significant slopes for the genetic trends of some wool traits were spurious. Genetic change in these traits was thus not compared to previous literature where genetic change in wool traits was strived for.

Table 2.15 Genetic trends from the literature for ovine birth and weaning weights. Direct and maternal genetic progress given as kg per annum with the percentage given in brackets.

Direct genetic progress (kg)	R^2 direct	Maternal genetic progress (kg)	R^2 maternal	Breed	Reference
Birth weight (kg)					
-0.002 (-0.07)*	0.09	-	-	Madras Red[a]	Balasubramanyam *et al*., 2012
0.002 (0.04)	0.73	0.002 (0.04)	0.84	Moghani[a]	Hossein-Zadeh, 2012
0.002 (0.06)	0.44	0.003 (0.09)	0.74	Kermani[b]	Mokhtari & Rashidi, 2010
0.006 (0.20)	-	-	-	Tropical fat tailed[c]	Negussie *et al*., 2002
0.006 (0.16)	-	-	-	Dorper[c]	Kariuki *et al.,* 2010
0.009 (0.02)	0.57	0.007 (0.17)	0.73	Makooei[b]	Mohammadi *et al*., 2012
-0.002 (-0.06)	0.42	-	-	Dormer[b]	Zishiri *et al*., 2010
0.001 (0.03)	-	-	-	Ile de France[b]	Zishiri *et al*., 2010
0.02	-	-	-	Kurdish[b]	Rashidi & Akheshi, 2007
0.002	-	0.005	-	Zandi[b]	Mohammadi et al., 2011
0.06 (2.00)*	-	-	-	Malpura[b]	Arora *et al.,* 2010
0.002 (0.05)	0.78	0.02 (0.54)	0.95	Arman[b]	Farokhad *et al*., 2011
Weaning weight (kg)					
0.07 (0.71)	0.41	-	-	Madras Red[a]	Balasubramanyam *et al*., 2012
0.07 (0.30)	0.85	0.05 (0.21)	0.80	Moghani[a]	Hossein-Zadeh, 2012
0.13 (0.63)	0.81	-	-	Kermani[b]	Mokhtari & Rashidi, 2010
0.04 (0.20)	-	-	-	Tropical fat tailed[c]	Negussie *et al*., 2002
0.10 (0.50)	-	-	-	Dorper[c]	Kariuki *et al.,* 2010
0.07 (0.31)	0.78	-	-	Makooei[b]	Mohammadi *et al*., 2012
0.04 (0.12)	-	-	-	Dormer[b]	Zishiri *et al*., 2010
0.34 (1.21)	-	-	-	Ile de France[b]	Zishiri *et al*., 2010
0.04	-	-	-	Ossimi[b]	Shaat *et al*., 2004
0.09	-	-	-	Rahmani[b]	Shaat *et al*., 2004
0.13	-	-	-	Kurdish[b]	Rashidi & Akheshi, 2007
0.10	-	-	-	Zandi[b]	Mohammadi et al., 2011
0.007 (0.03)	0.79	0.007 (0.03)	0.94	Arman[b]	Farokhad *et al*., 2011
Post weaning weight (kg)					
0.12 (0.57)	0.57	-	-	Madras Red[a]	Balasubramanyam *et al*., 2012
0.11 (0.28)	0.76	0.01 (0.03)	0.72	Moghani[a]	Hossein-Zadeh, 2012
0.16 (0.67)	0.71	-	-	Kermani[b]	Mokhtari & Rashidi, 2010
0.09 (0.30)	-	-	-	Tropical fat tailed[c]	Negussie *et al*., 2002
0.16 (0.44)	-	-		Dorper[c]	Kariuki *et al.,* 2010
0.05 (0.12)	0.88	-	-	Makooei[b]	Mohammadi *et al*., 2012
0.46 (1.69)	-	-	-	Malpura[b]	Arora *et al.,* 2010
0.04	-	-	-	Zandi[b]	Mohammadi et al., 2011
0.15 (0.26)	0.72	-	-	Dohne Merino[e]	Cloete *et al*., 1998a
0.63 (1.20)	0.94	-	-	Merino[d]	Olivier *et al*., 1995

[a] – Selected for body weight; [b] – Undefined; [c] – Unselected; [d] – Selected for clean fleece weight with limitations on fibre diameter; [e] – Selected for increase body weight, decrease fibre diameter and maintain clean fleece weight; * - not significant; R^2 – Coefficient of determination

Estimates for annual genetic change in birth weight from previous studies (Table 2.15) reported a range of estimates from -0.07 to 2.00% (n = 12). The estimate from the current study (0.002%) fitted on the lower end of this range. The maternal genetic change was calculated as an increase of 0.078% in Table 2.14 - an estimate that was within the range of 0.04 to 0.54% p.a. as summarised from previous estimates (n = 5; Table 2.15).

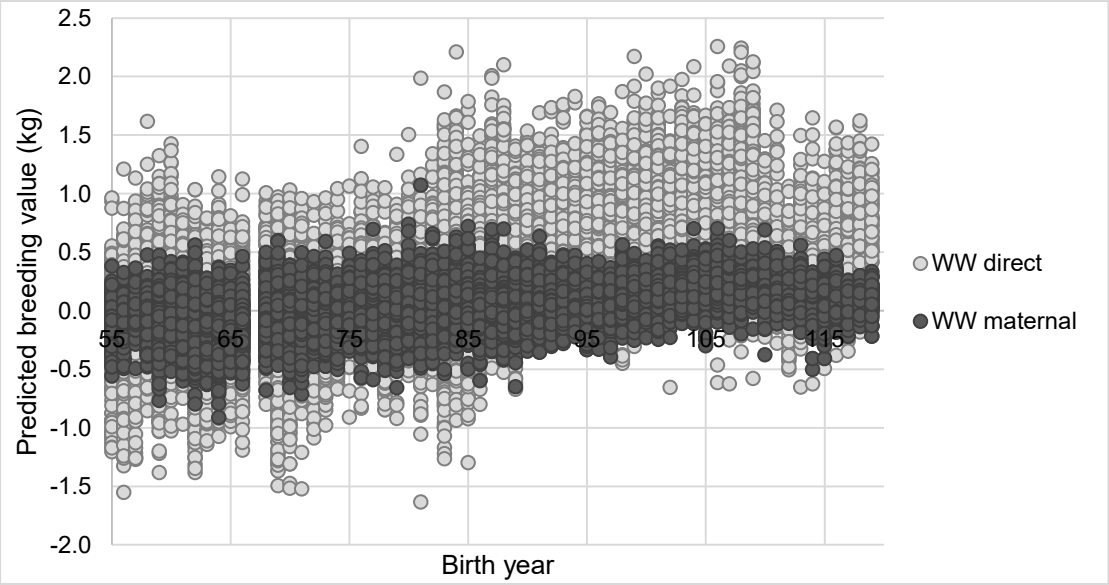

Figure 2.3 Scatterplot depicting direct and maternal predicted breeding values for weaning weight from 1955 to 2019.

The direct genetic change for weaning weight (0.078% p.a. in Table 2.14) fitted on the lower end of a comparable range of 0.03 to 1.21% p.a. from 13 literature sources, with most studies reporting a faster rate of genetic change (Table 2.15). The maternal genetic change in the SAMM flock analysed amounted to 0.018% p.a. (Table 2.14). Table 2.15 reported only 2 estimates for maternal genetic change in weaning weight ranging from 0.03 to 0.21% p.a. to compare our results with. The SAMM flock studied recorded genetic gains of respectively 0.088 and 0.076% p.a. in yearling weight, as discussed previously (Table 2.14). This rate of gain compared unfavourably with comparable rates of genetic progress in previous studies that ranged from 0.12 to 1.69% p.a. for post-weaning weight (n = 10; Table 2.15).

2.4 Conclusion

Early growth traits (and weaning weight in particular at 103 ± 8 days of age) of the SAMM lambs were lowly heritable, potentially constraining efforts to change these traits by genetic selection. The yearling traits had higher heritability estimates. Genetic and phenotypic

correlations among the yearling traits were low to moderately high with very few obviously unfavourable correlations. The most important of these was the known unfavourable correlations of fleece weight, live weight and staple length with fibre diameter. Derived estimates of genetic change for all traits were disappointingly low, suggesting that these objective traits were not included during the selection of replacements in this flock. Future research should target reasons for the culling of animals based on subjectively assessed traits during subjective selection according to breed standards.

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Chapter 3
Genetic and environmental parameters and trends for early growth and yearling traits of the Elsenburg Dormer resource flock

Abstract

The Dormer is a composite breed and constitutes the most numerous terminal sire breed in South Africa. The Elsenburg Dormer flock is the foundation flock of the breed and is still being maintained at the Elsenburg Research Farm in the Western Cape province of South Africa. Data from 1943 to 2019 were used to investigate genetic and environmental parameters and trends for early growth traits and lamb survival (LS) in the flock. Yearling live weight- and wool traits were recorded for a shorter period from 2008 to 2018. REML-procedures were used to estimate fixed effects as well as genetic parameters and trends in the flock. The fixed effects of birth year, sex, birth type and age of dam had a significant influence on all the early growth traits. There was an interaction between birth year and sex for most traits. Direct single-trait heritability estimates were 0.15 for birth weight (BW), 0.06 for weaning weight (WW), 0.02 for LS, 0.19 for yearling weight (YW), 0.63 for clean yield, 0.56 for clean fleece weight, 0.59 for staple length, 0.59 for staple strength, 0.60 for coefficient of variation of fibre diameter and 0.80 for fibre diameter. Maternal genetic effects amounted to 0.21 for BW, 0.08 for WW and 0.06 for YW. Dam permanent environmental effects ranged from 0.03 for LS to 0.08 for BW and litter effects from 0.12 for LS to 0.28 for BW. Multi-trait heritability estimates were fairly consistent with the above single-trait estimates. Genetic correlations among live weight traits ranged from low (-0.11) for BW and YW to very high (0.93) for WW and YW. Genetic correlations of YW with wool traits ranged from low to moderate. Genetic correlations among wool traits were mostly consistent with literature estimates for wool breeds. Genetic trends for all weight traits suggested a significant positive trend with time. Expressed relative to the overall phenotypic mean, these trends amounted to 0.12% for BW, 0.16% for WW and 0.45% for YW. This study concluded that all traits were heritable and variable. Purposeful selection for a well-defined objective should allow faster genetic improvement than the annual rates of gain that were realised.

3.1 Introduction

Improved technology and upgrades to the existing software for genetic parameter estimation herald continuous upgrades to industry selection strategies to meet the ever changing needs of the breeding industry and consumers alike. Animal breeding scientists seek to increase the genetic improvement rate of economically important traits through well-directed

selection. According to Safari e*t al.* (2005) the breeding objectives for sheep are becoming more complex. Large sets of data are required to obtain accurate estimates of genetic correlations and variances (Safari *et al*., 2007). Genomic selection allows for more accurate selection of ovine livestock (Cloete *et al*., 2014), but the potential of this methodology has not yet been realized in this species in South Africa (Van Marle-Köster & Visser, 2018). Seeing that South African sheep is potentially on the brink of a genomic revolution, it is imperative that genetic parameters of resource populations with extended phenotypes (Schoeman *et al*., 2010) that could potentially contribute to a genomic reference population are revisited.

One such flock is the Elsenburg Dormer flock (Van Wyk *et al*., 2003; Schoeman *et al*., 2010). The Dormer breed was developed at the Elsenburg Research Farm in the 1940's, when Dorset Horn rams were crossed with the then German Merino ewes to establish a composite, synthetic breed. These crosses formed the basis of the Dormer breed, which became the numerically most important terminal sire breed for usage on wool breeds in South Africa (Zishiri *et al*., 2010; Cloete *et al*., 2014). The Dormer is considered to display favourable growth and meat production characteristics (Van der Merwe *et al*., 2019). Although the Dormer is known as a coarse wool breed, no quantitative studies have so far been conducted on its fleece characteristics. Early growth in the Elsenburg Dormer flock has been studied extensively by Van der Merwe (1976). Later studies on early growth considered systematic environmental effects (Van Wyk *et al*., 1993a), direct and maternal genetic variance components and ratios (Van Wyk *et al*., 1993b), genetic and environmental correlations (Van Wyk *et al*., 1993d) as well as genetic and environmental trends (Van Wyk *et al*., 1993e). These studies were updated by Van Wyk *et al*. (2003) after more records were added and a litter effect was additionally computed for early growth and lamb survival. A more comprehensive dataset from this resource flock was used for this study. Which, include more records for birth weight, lamb survival and weaning weight, while the analyses were also extended to cover yearling live weight and wool traits for the first time.

Against this background, the aim of this study was to update genetic and environmental parameters and trends for early live weight and lamb survival and to include records on yearling live weight and fleece traits in the estimation.

3.2 Materials and methods

3.2.1 Animal resources, the environment and management

The Elsenburg Dormer flock is an important local resource flock and are described thoroughly in the literature (Van der Merwe, 1976; Van Wyk *et al*., 1993a; 1993b; 1993c; 1993d; 1993e; Schoeman *et al*., 2010). The flock was maintained on the Elsenburg Research Farm throughout the study. Elsenburg is situated about 10km outside of Stellenbosch in the Western Cape in a winter rainfall environment with an average annual rainfall of 642 mm, 78% of which is expected between and including April and September. GPS coordinates of Elsenburg is 33° 51' S and 18° 30' E and the farm is approximately 177 m above sea level. The stud consisted of between 120 and 180 breeding ewes over time.

The ewe flock mostly grazed on irrigated kikuyu (*Pennisetum clandestinum*) paddocks when mated in single-sire groups during spring to lamb in autumn (Cloete *et al*., 1998b). Lambing also took place on irrigated kikuyu paddocks, but the ewes and their lambs were drifted off to irrigated lucerne (*Medicago sativa*) paddocks within 3 to 14 days after lambing. Based on the results of Cloete (1992) the number of pregnant ewes per hectare was controlled at about 30 or less. After tail docking the lambs (11 - 21 days of age) the ewes and their progeny were moved to bigger paddocks in groups of 20 - 40 ewes and their progeny per paddock. The rest of the production cycle up to weaning took place mostly on dryland lucerne pastures and oat (*Avena sativa*) fodder crops (Cloete *et al*., 1998b). Weaner lambs continued to graze on lucerne and oats wherever possible, while the ewe flock was mostly maintained on irrigated kikuyu during the dry period. Management practices changed over the 77 years due to drought and available infrastructure, but it was attempted to provide a fairly uniform environment to all cohorts produced in the flock as far as was possible.

3.2.2 Data recorded and selection practices implemented

Lambs were identified together with their dams and a birth weight was recorded within 24 hours of birth (Cloete, 1993). Weaning weights were recorded at a mean (±SD) age of 102 ± 8 days. It was possible to derive lamb survival, as a trait of the lamb, from birth to weaning from birth and rearing records. All lambs were shorn as weaners at about 5 to 6 months of age throughout the duration of data recording. Lambs were shorn again at 362 ± 42 days of age from 2008 to 2019. Greasy fleece weight and yearling weight after shearing were recorded at this stage. A mid-rib wool sample was taken simultaneously to determine clean yield, fibre diameter, staple length, staple strength and the coefficient of variation of fibre diameter. Clean fleece weight was derived from greasy fleece weight and clean yield. Clean fleece weight and staple length records were adjusted to a constant growth period of 365 days.

Initially the flock was closed to outside genetics, but external sires were introduced from 1997, when three unrelated rams were introduced to lower the level of inbreeding (Van Wyk *et al*., 1993c; 2009). External sires were occasionally introduced in subsequent years, to ensure that inbreeding was managed in a reasonable range. Initially, selection was mostly based on conformation. Lamb growth, on indexes at first and subsequently on breeding values, attracted more attention in the later years (Van Wyk *et al*., 1993e; Chapter 4). The replacements that were selected had to conform to breed standards throughout. This resulted in relative mediocre genetic gains up to the early 1990's (Van Wyk *et al*., 1993e). Sires were used for a maximum of two years consecutively and ewes were initially cast for age at 6 to 7+ years of age, or with severe udder or teeth malfunction. The number of ewe age groups was, however, reduced to 5 (2 to 6 years) in recent years.

3.2.3 Statistical analysis

Fixed effects affecting the production traits were assessed in preliminary runs. Fixed effect models included birth year (1943 – 2019) for early weights and lamb survival, 2008 - 2018 for yearling traits), sex (male or female), age of dam (2 to 7+ years), birth type (single, twin or triplet) and two-factor interactions between traits. Animal age was included as a linear regression in analyses on weaning and yearling weights. Lamb survival was analysed with or without the inclusion of linear and quadratic regressions on birth weight. All the statistical analyses were conducted in ASREML (Gilmour *et al*., 2016). A *P*-value of < 0.05 was regarded as significant when tasting fixed effects in single-trait analyses. Only the significant fixed effects for early growth traits and yearling traits were then included in the final operational models that were used for the assessment of random effects.

Table 3.1 summarised the random terms, which included a combination of direct additive, maternal additive, dam permanent environmental and litter effects, as well as the covariance between direct and maternal additive effects that were sequentially added for early growth traits. Yearling traits included the same random effects with the exception of litter. This resulted in nine potential single-trait mixed animal models for early growth traits and six potential single-trait mixed animal models for yearling traits in matrix notation.

Table 3.16 Description of the number of models used for early growth and yearling traits for the Elsenburg Dormer flock in matrix notation.

Models	Early growth traits	Yearling traits
$y = Xb + Z_1a + e$	1	1
$y = Xb + Z_1a + Z_2c + e$	2	2
$y = Xb + Z_1a + Z_3m + e$ [Covariance (a,m)=0]	3	3
$y = Xb + Z_1a + Z_3m + Z_2c + e$ [Covariance (a,m)=0]	4	4
$y = Xb + Z_1a + Z_4l + Z_2c + e$	5	
$y = Xb + Z_1a + Z_3m + Z_4l + Z_2c + e$ [Covariance (a,m)=0]	6	
$y = Xb + Z_1a + Z_3m + e$ [Covariance (a,m)=Aσ$_{am}$]	7	5
$y = Xb + Z_3a + Z_3m + Z_2c + e$ [Covariance (a,m)=Aσ$_{am}$]	8	6
$y = Xb + Z_3a + Z_3m + Z_2c + Z_4l + e$ [Covariance (a,m)=Aσ$_{am}$]	9	

In these analyses, y = a vector of observations for the respective traits, b = vector of fixed effects, a = the direct genetic variance, m = the maternal genetic variance, c = the dam permanent environmental variance, l = the litter variance, X, Z_1, Z_2, Z_3 and Z_4 = the corresponding incidence matrices relating the respective effects to y, e = a vector of residuals, A = the numerator relationship matrix and σ_{am} = the covariance between direct genetic and maternal genetic effects.

It was assumed that,

$$V(a) = A\sigma^2_a;\ V(m) = A\sigma^2_m;\ V(c) = I\sigma^2_c;\ V(l) = I\sigma^2_l;\ V(e) = I\sigma^2_e$$

Where, A = the numerator relationship matrix denoting relationships among animals in the pedigree file, I = identity matrices, σ^2_a = the direct genetic variance, σ^2_m = the maternal genetic variance, σ^2_c = the dam permanent environmental variance (the correspondence between lambs of the same dam across lambing years), σ^2_l = the variance attributed to the litter effect (the correspondence between lambs of the same dam within lambing years) and σ^2_e = the environmental (residual) variance. The pedigree file used in the analyses included 14929 animals, the progeny of 387 sires and 3283 dams.

Random effects for both early growth and yearling traits were tested for significance using log likelihood ratio tests after the sequential inclusion of the random effects in Table 3.1 to the operational fixed-effect model used to analyse each trait. A random effect was regarded as significant when its inclusion in the model caused a significant improvement in the observed log likelihood ratio ($P < 0.05$). The Chi-square distribution of α = 0.05 at one degree of freedom was used as a test statistic (3.841). When -2 times the difference between the log likelihoods was greater than this critical value, the inclusion of the particular random effect was considered to

improve the fit significantly (Swalve, 1993). Various models were tested for significance to identify the best and simplest models that could be used for subsequent two- and multi-trait runs. These analyses were conducted to estimate the genetic, phenotypic and environmental correlations for live weight traits (birth, weaning and yearling weight). Appropriate correlations were also computed between birth weight and lamb survival. As all animals with weaning weight and subsequent records survived, it was not attempted to relate lamb survival to the other traits. Finally, a six-trait analysis was conducted to estimate the genetic, phenotypic and environmental correlations among the yearling traits.

Direct- and maternal animal solutions from multi-trait models were obtained from the analyses and used to derive direct and maternal genetic trends, where applicable. Individual breeding values were regressed on birth years to reflect the accrued genetic gains of all traits. Genetic trends were depicted as graphs where appropriate.

Ethical clearance for this study was obtained from the Departmental Ethics Committee for Research on Animals (DECRA) of Western Cape Department of Agriculture (reference number R12/55).

3.3 Results and Discussion

3.3.1 Descriptive statistics

The descriptive statistics of the traits studied are presented in Table 3.2. Traits analysed were birth weight, weaning weight and lamb survival that were recorded over the entire experimental period from 1943 to 2019. The yearling traits recorded for progeny groups from 2008 to 2018 included yearling weight, clean yield, clean fleece weight, staple length, staple strength, coefficient of variation of fibre diameter and fibre diameter.

Data of between 12030 and 14544 animals were considered for early lamb traits with CVs ranging from 22.2% for weaning weight to 45.5% for lamb survival (Table 3.2). Data of between 711 records for staple strength and 1703 animals for yearling live weight were considered for yearling traits. The CVs of these traits were relatively high at > 0.20 for clean fleece weight and staple strength. In contrast, the CV for clean yield and fibre diameter were below 10.0%. The CVs were in accordance with those of Cloete *et al*. (2004) for yearling weight and wool traits for South African Mutton Merino sheep. It is also similar to the CVs of wool traits of the Elsenburg Merino flock (Matebesi-Ranthimo *et al*., 2017). The CVs of the early growth traits are in accordance with those of Van Wyk *et al*. (2003) for Elsenburg Dormer sheep. Safari e*t al*. (2005) found the CVs of dual-purpose sheep for birth weight, weaning weight and lamb survival to be 16.5, 15.9 and 47.0%, respectively. Corresponding CVs in the review of Fogarty (1995)

amounted to 17.0, 15.0 and 46.0%, respectively. These values for the weight traits were lower than those of the current study, but the CV for lamb survival was similar. Safari *et al.* (2005) recorded a CV for yearling weight (10.6%) which was similar to the value of 10% reported by Fogarty (1995). These values were in accordance with those of the current study. The CVs of wool traits were similar to those of Safari e*t al.* (2005). The latter study recorded CVs for clean yield, clean fleece weight, staple length, staple strength, coefficient of variation of fibre diameter and fibre diameter of respectively 6.0, 20.8, 14.0, 29.2, 12.2 and 7.2% in dual-purpose sheep.

Table 3.2 Descriptive statistics for early growth and yearling traits in the Elsenburg Dormer flock.

Trait	n	Mean	SD	CV (%)	Range
Early growth traits					
Birth weight (kg)	14524	3.93	0.86	25.4	0.5 - 8.5
Weaning weight (kg)	12030	29.1	6.46	22.2	7.0 - 52.0
Lamb survival	14544	0.83	0.38	45.5	0 - 1
Yearling traits					
Yearling weight (kg)	1703	51.4	7.41	14.4	22.5 - 75.5
Clean yield (%)	1548	73.9	5.71	7.73	54.6 - 89.1
Clean fleece weight (kg)	1484	2.09	0.42	20.1	0.76 - 3.79
Staple length (mm)	1551	106.0	18.7	17.6	53 - 210
Staple strength (N/ktex)	711	42.2	9.62	22.8	12.6 - 78.0
CV of fibre diameter (%)	1551	18.3	1.97	10.8	12.7 - 27.8
Fibre diameter (µm)	1551	28.8	2.39	8.30	21.6 - 36.2

n: number of records; SD: standard deviation; CV: coefficient of variation

When coarse-wool breeds were considered, the means from Brash *et al*. (1994a) for Corriedale sheep were comparable to those in the current study; namely 24.9 kg for weaning weight, 50.1 kg for yearling weight, 73.9% for clean yield, 2.56 kg for clean fleece weight and 25.0 µm for fibre diameter. Comparable results were also found by Morris *et al.* (1996) for Romney sheep for birth weight (4.1 kg), weaning weight (18.7 kg), yearling weight (38.2 kg), clean yield (77.2%), clean fleece weight (2.27 kg), staple length (130.0 mm) and fibre diameter (31.5 µm) as well as by Pickering *et al*. (2012) for fibre diameter (34.6 µm) and the coefficient of variation of fibre diameter (23.9%). The results of Scobie *et al*. (2012) for Romney sheep corresponded well with those in the current study; namely 49.6 kg for yearling weight, 74.1% for clean yield, 2.41 kg for clean fleece weight, 149.0 mm for staple length and 33.6 µm for fibre diameter as well as with the results from Wuliji *et al*. (2011); namely 22.1 kg for weaning weight, 73.1% for clean yield, 1.98 kg for clean fleece weight, 119.0 mm for staple length, 34.2 N/ktex for staple strength and 35.2 µm for fibre diameter. The means for birth weight, weaning weight and post weaning weight of Dormers reported by Zishiri *et al*. (2014) were also consistent with the current study.

3.3.2 Environmental effects denoted by predicted fixed effect means

Table 3.3 predicted the means for the fixed effects of sex, birth type and dam age on early growth traits and lamb survival. Birth weight was affected by birth year, sex, birth type and age of dam (P <0.001; Table 3.3). There was a significant interaction between birth year and sex for birth weight (P <0.05). Male lambs generally weighed more than female lambs except for a few years when birth weight was independent of sex (Figure 3.1). Birth weight increased from a dam age of 2 years before stabilising for ewes of 5 to 7+ years. These results are in agreement with those of Fourie & Heydenrych (1982), Cloete & De Villers (1987), Cloete *et al.* (1998a), Fair (2002) and Knuth *et al.* (2018). The birth and weaning weights of males and singles were significantly higher than those of females, twins and triplets in particular (P <0.01; Table 3.3). Dams with ages between 3 and 6 years had heavier lambs at weaning with an average weight of approximately 28.3 kg. Dams belonging to the youngest (2 years) and oldest (7+ years) dam age groups had smaller lambs at weaning. The linear regression of weaning weight on weaning age was used to adjust lamb weaning weight data for age differences. Weaning weight increased with 0.14 kg per day of age (Table 3.3). These results were consistent with respective values of 0.10 and 0.21 kg per day of age (Brash *et al*., 1994a; Brash *et al*., 1994b).

Table 3.3 Predicted means (±SE) depicting the fixed effects of sex, birth type and dam age on early growth traits and lamb survival in the Elsenburg Dormer flock.

Effects and levels	Birth weight (kg)	Weaning weight (kg)	Lamb survival (BW included)	Lamb survival (BW excluded)
Sex				
Male	3.85 ± 0.04	28.92 ± 0.41	0.79 ± 0.02	0.75 ± 0.02
Female	3.57 ± 0.04	26.70 ± 0.37	0.82 ± 0.02	0.77 ± 0.02
P-value	***	***	*	*0.11*
Birth type				
Singles	4.50 ± 0.01	33.09 ± 0.08	0.87 ± 0.01	0.88 ± 0.01
Twins	3.76 ± 0.01	27.08 ± 0.06	0.86 ± 0.01	0.81 ± 0.01
Triplets	2.88 ± 0.10	23.25 ± 0.81	0.67 ± 0.11	0.59 ± 0.05
P-value	***	***	**	***
Age of dam (years)				
2	3.34 ± 0.04	26.27 ± 0.28	0.82 ± 0.04	0.75 ± 0.02
3	3.64 ± 0.04	28.05 ± 0.28	0.81 ± 0.04	0.77 ± 0.02
4	3.76 ± 0.04	28.73 ± 0.28	0.81 ± 0.04	0.77 ± 0.02
5	3.81 ± 0.04	28.52 ± 0.29	0.81 ± 0.04	0.78 ± 0.02
6	3.88 ± 0.04	28.05 ± 0.31	0.78 ± 0.04	0.76 ± 0.02
7+	3.85 ± 0.04	27.24 ± 0.32	0.77 ± 0.04	0.74 ± 0.02
P-value	***	***	**	*
Regressions				
Birth weight (L)	-	-	0.358 ± 0.038	-
Birth weight (Q)	-	-	-0.035 ± 0.004	-
Weaning age	-	0.14 ± 0.01	-	-

* P < 0.05; ** P < 0.01; *** P < 0.001; actual significance for P > 0.05

The effect of the interaction between birth year and sex are illustrated in Figure 3.2. It is evident from this figure that weaning weight was affected by the interaction (*P* <0.05). It was evident that males and females differed less in weight at weaning in some years than in others and could be ascribed to differences in managerial practices in the past. There was a significant interaction between the sex and birth type (*P* <0.05). Male lambs were heavier than females for singles and twins, but no conclusive sex effect was evident for triplets (*P* >0.05). This result could stem from the relatively small number of triplets analysed. Results from Van Wyk *et al*. (1993a), Cloete & De Villiers (1987), Cloete *et al.* (1998a), Fair (2002), Wuliji *et al*. (2011) and Knuth *et al*. (2018) all supported the present findings.

Lamb survival was improved in female lambs when the linear and quadratic effects of birth weight were modelled (P <0.05; Table 3.3) but not in the absence of birth weight. Female lambs were previously shown to have higher survival rates than males (Hight & Jury, 1970; Dalton *et al*., 1980; Cloete *et al*., 2001; Everett-Hincks *et al*., 2014). These results corresponded well with those of twins and triplets in particular which had a poorer survival rates than singles (P <0.01) in an analysis excluding the linear and quadratic regressions of survival on birth type. Including birth type in the analysis reduced the difference between singles and twins to be insignificant, but both birth type classes still differed from triplets.

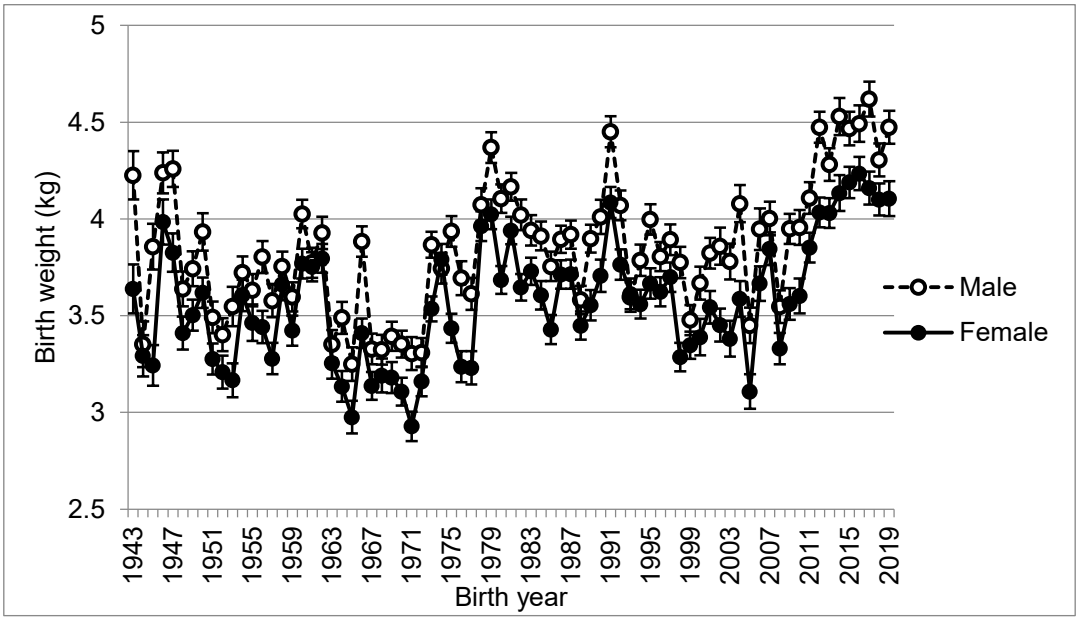

Figure 3.1 Predicted means (±SE) illustrating the interaction between birth year and sex for birth weight of the Elsenburg Dormer resource flock from 1943 to 2019. The vertical lines about means denote standard errors.

The survival of the progeny of the oldest dam age group was lower relative to the progeny of 5-year-old ewes (Table 3.3). The best survival for all birth type classes was found in lambs with an intermediate birth weight, while those lambs with extremely high and low birth weights were more likely to succumb (Figure 3.3). The fixed effects of lamb survival for birth type and age of

dam were in accordance with that reported for other studies (Hight & Jury, 1970; Dalton *et al*., 1980; Lopez-Villalobos & Garrick, 1999; Cloete *et al*., 2001; Everett-Hincks *et al*., 2014).

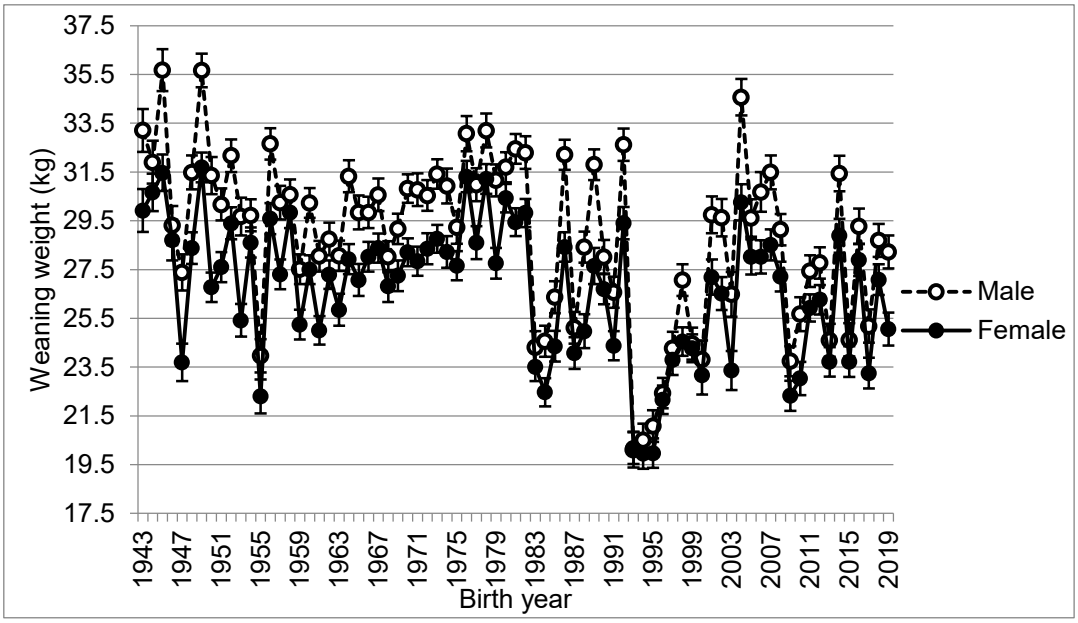

Figure 3.2 Predicted means illustrating the interaction between birth year and sex for weaning weight of the Elsenburg Dormer resource flock from 1943 to 2019. The vertical lines about means denote standard errors.

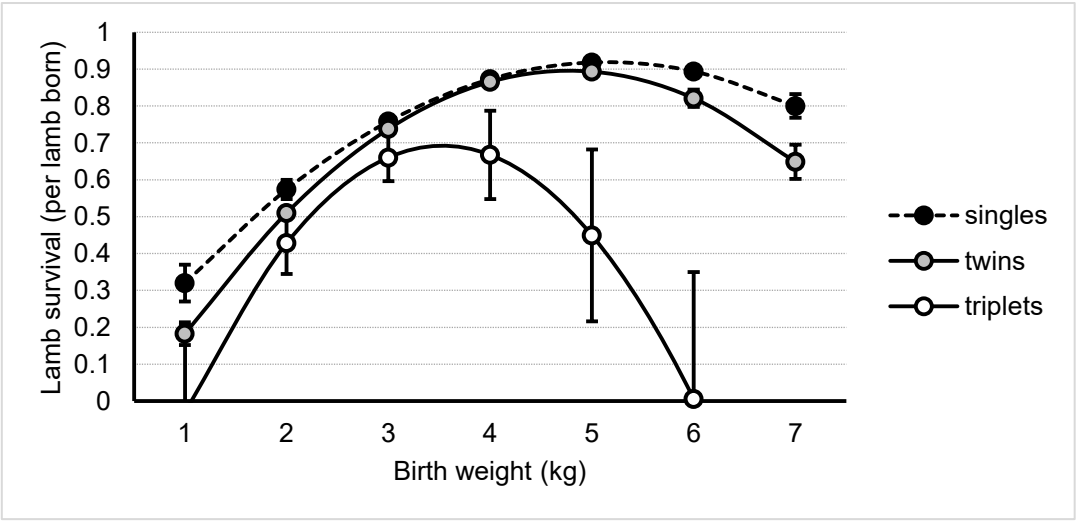

Figure 3.3 Predicted means illustrating the interaction of the quadratic regression of lamb survival on birth weight for different singles, twins and triplets in the Elsenburg Dormer resource flock. The vertical lines about means denote standard errors.

Birth year influenced all yearling traits (P <0.01) and were often involved in an interaction with sex. This was expected as yearlings were maintained in flocks separated on sex from weaning onwards. It is understandably difficult to ensure that grazing conditions are similar for both the ewe and ram flocks (Brash *et al*., 1994a; 1994b; Cloete *et al*., 1998a), contributing to the sex by birth year interaction. Birth year effects are thus not tabulated as birth years are transient and not repeatable. This stands to reason, since birth year effects depend on a

combination of unique climatic and managerial effects. As for other traits, birth year interacted with sex for yearling weight. This interaction is presented in Figure 3.4 as an example since it would be superfluous to provide all similar interactions. It was evident from Figure 3.4 that male yearlings were generally heavier than females (P <0.05), although the magnitude of this sex difference varied according to year with no significant sex effect in 2012 (P >0.05). In other years the sex effects ranged from approximately 5 to 15% in favour of rams. It was noted that the period from 2009 to 2012 was characterised by markedly lower (P <0.05) weights than the period before and after it. This period coincided with a stage when the re-establishment of new dryland lucerne paddocks failed, and animals were maintained longer on dryland lucerne paddocks with a sparse stand as well as kikuyu paddocks in lower-lying areas. This probably resulted in the reduction of live weight during this period. It should be noted that the period from 2015 to 2018 was uncharacteristically dry. However, the diets of the yearlings were supplemented with roughage (mostly lucerne hay that was either produced on-farm or bought in) to the extent that yearling weights were as before 2009. The linear regressions of yearling weight on yearling age were used to adjust data within birth years for age differences since the birth year by yearling age interaction was significant (P <0.01). Overall, yearling live weight increased on average with 0.22 kg per day of age across all years from 2007 to 2018 (Table 3.4). Ram and single yearlings were heavier than ewes, twins and triplets (P <0.01). The yearling live weights of the progeny of the youngest and oldest dams were compromised, compared to the progeny of the dams of 4 to 6 years of age (P <0.01). Results from Brash *et al.* (1994a; 1994b) were in agreement with the present results except for the magnitude of the age regressions (0.08 and 0.11 kg/day respectively). Results from Cloete *et al.* (1998a) and Wuliji *et al*. (2011) were also in accordance with those of the current study.

Overall, ewe yearlings had a higher average clean yield than rams (P <0.01; Table 3.4), while clean yield was unaffected by birth type and dam age. Ewe yearlings had a heavier clean fleece weight than rams, while clean fleece weight decreased from singles to triplets (P <0.001). The higher clean fleece weight of ewe yearlings relative to rams was not expected, as results in the literature suggest the opposite (Cloete *et al*., 1998a; 1999). This result can be explained by differential management of the more resilient ram flock as compared to the ewes. This often entailed that they were grazed on poorer pastures with adult rams, as reflected by the average advantage of only 8.6% in yearling weight (Table 3.4). Previous results suggested that rams should be up to 28.9 to 45.5% heavier than ewes at the yearling and hogget stages (Cloete *et al*., 1998a; 1999; 2004).

Table 3.4 Predicted means (±SE) of the fixed effects for yearling weight and wool traits from the Elsenburg Dormer flock.

Effects and levels	Yearling weight (kg)	Clean yield (%)	Clean fleece weight (kg)	Staple length (mm)	Staple strength (N/ktex)	Coefficient of variation of fibre diameter (%)	Fibre diameter (µm)
Sex							
Male	55.4 ± 0.84	72.3 ± 0.44	2.02 ± 0.04	100 ± 1.08	40.5 ± 1.00	18.3 ± 0.18	29.0 ± 0.04
Female	51.0 ± 0.84	75.2 ± 0.38	2.13 ± 0.03	108 ± 1.06	40.2 ± 0.96	18.1 ± 0.15	29.4 ± 0.18
P-value	***	***	***	**	*0.70*	***	***
Birth type							
Singles	57.8 ± 0.75	73.7 ± 0.31	2.20 ± 0.03	104 ± 0.78	42.4 ± 0.78	18.0 ± 0.12	29.1 ± 0.14
Twins	52.7 ± 0.73	73.7 ± 0.24	2.10 ± 0.02	106 ± 0.61	41.7 ± 0.63	18.7 ± 0.10	29.1 ± 0.11
Triplets	49.1 ± 1.33	73.9 ± 0.98	1.93 ± 0.08	103 ± 2.69	36.9 ± 2.26	18.0 ± 0.39	29.4 ± 0.45
P-value	***	*0.97*	***	*	*0.056*	***	*0.55*
Age of dam (years)							
2	51.3 ± 0.84	73.6 ± 0.41	1.95 ± 0.03	103 ± 0.10	39.8 ± 1.01	18.0 ± 0.16	28.9 ± 0.19
3	52.7 ± 0.84	73.9 ± 0.41	2.03 ± 0.03	103 ± 1.08	41.1 ± 0.95	17.9 ± 0.16	29.1 ± 0.19
4	53.6 ± 0.85	74.1 ± 0.41	2.06 ± 0.03	102 ± 1.08	40.0 ± 0.93	18.0 ± 0.16	29.0 ± 0.19
5	53.5 ± 0.86	74.0 ± 0.44	2.08 ± 0.04	103 ± 1.17	41.0 ± 1.09	18.2 ± 0.17	29.1 ± 0.20
6	54.9 ± 1.19	73.0 ± 0.94	2.27 ± 0.08	109 ± 2.60	39.8 ± 2.62	19.0 ± 0.37	30.0 ± 0.43
7+	51.3 ± 0.84	-	-	-	-	-	-
P-value	***	*0.52*	***	*0.33*	*0.58*	**	*
Regression on yearling age	0.22 ± 0.07	-	-	-	-	-	-

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; actual significance for $P > 0.05$

Clean fleece weight increased from 1.95 kg for the progeny of 2-year-old dams to 2.27 kg for the progeny of 6-year-old dams (P <0.01). The staple length of ram and ewe yearlings differed in favour of ewes, while twins had slightly longer staples than singles and triplets. The longer staple length of ewes was not expected as this trait was independent of sex in previous studies (Cloete *et al*., 1998a; 1999). The same explanation as offered for clean fleece weight could also justify this result. Staple strength was not significantly affected by sex and dam age, but there was a suggestion (P =0.056) that singles had a better staple strength than triplets (Table 3.4). Ram yearlings and twins had a slightly higher coefficient of variation of fibre diameter than ewes, singles and triplets (P <0.05) respectively. The coefficient of variation of fibre diameter varied from 17.9% for the progeny of 3-year-old dams to 18.9% for the progeny of 6-year-old dams (P <0.05). Ewe yearlings and the progeny of older dams had stronger wool than rams and the progeny of younger dams (Table 3.4). Birth type did not exert a significant influence on fibre diameter (P >0.05). Brash *et al*. (1994a) reported similar results for the effect of birth type on fibre diameter wherein single lambs showed the smallest microns followed by triplets. The current study recorded similar results for clean fleece weight, clean yield, staple

length and fibre diameter when compared to results presented by Cloete *et al.* (1998a) and Wuliji *et al*. (2011).

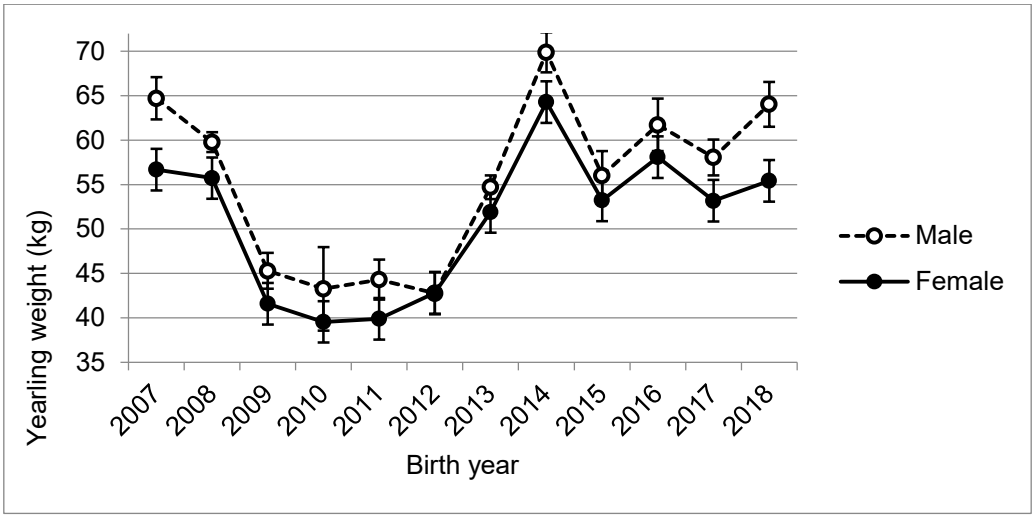

Figure 3.4 Predicted means illustrating the interaction between sex and birth year for yearling weight of the Elsenburg Dormer resource flock from 2007 to 2018. The vertical lines about means denote standard errors.

3.3.3 Log likelihood values

The random-effects models of choice for the early growth and yearling traits are presented in Table 3.5 and Table 3.6 respectively. The most suitable model for birth weight included all the random sources of variation considered, namely the direct genetic effect, maternal genetic effect, dam permanent environmental effect and, litter effect as well as the genetic correlation between animal effects. The best model for weaning weight included direct additive, maternal genetic, dam permanent environment and litter as random effects. The best model for lamb survival included direct additive, dam permanent environment and litter as random effects.

The modelling for the latter traits were not completely consistent with models reported by Cloete *et al*. (2001) for a Western Australian Merino resource flock and Van Wyk *et al*. (2003) on the same Dormer flock. Both the current study and that of Cloete *et al*. (2001) included direct additive, maternal additive and dam permanent environment in the models. Owing to the structure of the data, Cloete *et al*. (2001) also included random paddock and between bloodline variances, whereas the current study also included litter (both traits) and the covariance between animal effects in the model (only for birth weight). The variation in lamb survival in the study of Cloete *et al*. (2001) was best accounted for by paddock, between bloodlines, direct additive and maternal additive variances.

Table 3.5 Log likelihood ratios for random effects model fitted to early growth traits and lamb survival of the Elsenburg Dormer flock with the best fitted model in bold.

Model	(Co)variance components	BW	WW	LS
0	Fixed effects	-2724.28	-4586.96	7298.74
1	h^2	-2169.18	-4447.52	7315.19
2	$h^2 + c^2$	-1672.65	-4305.28	7345.19
3	$h^2 + m^2$	-1622.87	-4311.55	7331.26
4	$h^2 + m^2 + c^2$	-1586.03	-4283.23	7345.53
5	$h^2 + c^2 + l^2$	-1304.85	-4202.26	***7386.15***
6	$h^2 + m^2 + c^2 + l^2$	-1219.89	***-4179.46***	7386.39
7	$h^2 + m^2 + r_{am}$	-1617.61	-4308.94	7331.79
8	$h^2 + m^2 + c^2 + r_{am}$	-1581.42	-4281.24	7346.94
9	$h^2 + m^2 + c^2 + l^2 + r_{am}$	***-1216.84***	-4177.68	7387.44

h^2: direct additive effect; c^2: dam permanent environment effect due to dam; m^2: maternal additive effect; l^2: litter size; r_{am}: genetic correlation between animal effects; BW: birth weight; WW: weaning weight; LS: lamb survival

Van Wyk *et al*. (2003) used the same models to analyse birth weight and weaning weight data that were used in this study. This is understandable as the former authors used 11743 birth weight and 9657 weaning weight records up to 2002 that were common to both studies. In contrast with the modelling for birth and weaning weight, the study of Van Wyk *et al*. (2003) only included direct additive and litter effects in the case of lamb survival. Cloete et al. (1998a) only included direct genetic, maternal genetic and the dam permanent environmental effects for birth weight and direct genetic and dam permanent environmental effects for weaning weight.

The best models for yearling live weight and the yearling wool traits were chosen according to the log likelihood ratios in Table 3.6. The best model for yearling weight included direct additive and maternal additive effects as random variables. The best models for the rest of the traits only included the direct additive effects as random. The modelling for clean yield, staple length, staple strength and the coefficient of variation of fibre diameter was consistent with the study of Matebesi-Ranthimo *et al*. (2017) on the Elsenburg Merino flock. In contrast, maternal genetic effects also contributed significantly to the variation in clean fleece weight and fibre diameter in the latter study. The log-likelihood ratios for yearling weight in the current study differed from those in the study of Cloete *et al*. (1998a), where only the direct genetic effect was included. However, modelling for the rest of the wool traits in the latter study were in agreement with the current study.

Table 3.6 Log likelihood ratios for random effects models fitted to yearling weight and wool traits of the Elsenburg Dormer flock with the best fitted model in bold.

Model	(Co)variance components	YW	CY	CFW	SL	SS	CVFD	FD
0	Fixed effects	-3810.85	-3067.44	605.11	-5019.24	-1933.78	-1782.85	-2020.79
1	h^2	-3778.41	***-2935.56***	***678.13***	***-4902.43***	***-1891.56***	***-1662.54***	***-1823.04***
2	$h^2 + c^2$	-3776.93	-2935.06	678.85	-4902.41	-1891.56	-1662.31	-1822.99
3	$h^2 + m^2$	***-3775.69***	-2935.07	678.88	-4902.43	-1891.50	-1661.69	-1822.81
4	$h^2 + m^2 + c^2$	-3775.64	-2934.96	679.02	-4902.41	-1891.50	-1661.69	-1822.81
5	$h^2 + m^2 + r_{am}$	-3775.29	-2935.00	NC	-4901.65	-1891.44	-1661.21	-1822.79
6	$h^2 + m^2 + c^2 + r_{am}$	-3775.24	-2934.92	NC	-4901.04	-1891.44	-1661.21	-1822.79

h^2: direct additive; c^2: dam permanent environment effect; m^2: maternal additive; r_{am}: genetic correlation between animal effects; YW: yearling weight; CFW: clean fleece weight; FD: fibre diameter; CVFD: coefficient of variation of fibre diameter; CY: clean yield; SL: staple length; SS: staple strength; NC: could not converge

3.3.4 Single- and multi-trait heritability estimates

As single traits, the heritability of birth weight and yearling weight was moderate at respectively 0.15 and 0.19, while the heritability of weaning weight was low at 0.06 (Table 3.7). When these traits were analysed together in a three-trait analysis, heritability estimates amounted to 0.16 for birth weight, 0.07 for weaning weight and 0.17 for yearling weight (Table 3.8). The total heritability was estimated at 0.26 for birth weight, 0.10 for weaning weight and 0.22 for yearling weight. The total heritability for birth weight corresponded with the estimate from Van Wyk *et al.* (1993b) for the same Dormer flock, but using less data, whereas the total heritability for weaning weight was lower than that of the latter study. The total phenotypic variance derived from the three-trait model increased from birth weight to yearling weight. It amounted to 0.56 for birth weight, 23.41 for weaning weight and 33.73 for yearling weight (Table 3.11). These values corresponded very well with those derived from single-trait analyses (Table 3.7 and 3.10). When analysed together with yearling wool traits, the heritability of yearling weight was estimated at 0.19 (Table 3.10). All the multi-trait heritability estimates involving weight traits were thus within 0.02 of those derived in corresponding single-trait analyses. A survey of comparable literature estimates, mostly involving dual-purpose, meat and coarse-wool breeds, indicated respective ranges of 0.04 to 0.39 for birth weight, 0.01 to 0.34 for weaning weight (Table 3.9) and 0.13 to 0.31 for yearling weight (Table 3.11). It is evident that both single and multi-trait estimates from the present study were well within the ranges reported by other researchers in comparable literature sources. The heritability of lamb survival was similar at 0.02 irrespective of whether birth weight was modelled or not (Table 3.7). A similar heritability of 0.02 ± 0.01 was obtained when lamb mortality was analysed in a two-trait model with birth weight (not tabulated). At 0.15 ± 0.02, the heritability of birth weight was also similar to those in Tables 3.7 and 3.8. An estimate of 0.02 for the heritability of lamb survival aligned with the range of 0.01 to 0.12 derived from the literature (Table 3.9).

The single-trait estimates for the maternal heritability of weight traits decreased with age, from 0.21 for birth weight to 0.08 for weaning weight and 0.06 for yearling weight (Table 3.7 and 3.10), which was in agreement with the results from Snyman *et al.* (1995) for Afrino sheep. Maternal heritability estimates derived from the three-trait analysis involving weight traits suggested that some variation was repartitioned to the maternal genetic variance component. This was particularly for the litter and dam permanent environmental variances that appeared to be repartitioned towards the maternal heritability (m^2) effect in the three-trait analysis involving all weight traits (Table 3.7 and 3.8).

Maternal heritability estimates from the three-trait analysis increased by 0.04 for birth weight, 0.03 for weaning weight and 0.05 for yearling weight. It is notable that the maternal heritability of yearling weight in the seven-trait analysis with the wool traits (Table 3.10) was similar to the corresponding single-trait estimate. It thus seemed that the three-trait analysis was predisposed to yield somewhat higher estimates of the maternal genetic variance ratios, for reasons that is not clear at present. Nevertheless, the maternal heritability for birth weight (0.21 to 0.25) and weaning weight (0.08 to 0.11) were within the corresponding ranges in the literature amounting to respectively 0.10 to 0.24 and 0.03 to 0.25 (Table 3.9). However, the range for yearling weight (0.06 to 0.11) was on the higher side and above the range of 0.01 to 0.08 in the literature (Table 3.11).

Dam permanent environmental variance ratios derived from single-trait analyses amounted to 0.08 for birth weight, 0.06 for weaning weight and 0.03 for lamb survival (Table 3.7). Corresponding three-trait estimates for weight traits were somewhat lower, amounting to 0.06 for birth weight and 0.04 for weaning weight. These estimates are consistent with respective ranges of 0.08 to 0.37 and 0.00 to 0.09 in the literature (Table 3.9). Snyman *et al*. (1995) also found the dam permanent environmental variance ratio for birth weight to be 0.12 in Afrino lambs. The litter variance ratio contributed most to the phenotypic variation for weaning weight and lamb survival and amounted to 0.17 to 0.28 for birth weight, 0.18 to 0.24 for weaning weight and 0.12 to 0.13 for lamb survival (depending on whether birth weight were modelled or not) (Tables 3.7 and 3.8). The litter variance ratio for lamb survival from a two-trait analysis with birth weight remained similar at 0.13.

The covariance ratio for the genetic correlation between animal effects amounted to -0.24 ± 0.09 for birth weight in the single-trait analysis (Table 3.7). The corresponding three-trait estimate involving all three weights yielded a similar estimate of -0.24 ± 0.07 (not tabulated). The Hampshire and Chios breeds also had negative genetic correlations between animal effects for birth weight, amounting to respectively -0.56 and -0.44 (Tosh & Kemp, 1994; Ligda *et*

al., 2000). The genetic correlation between animal effects for birth weight was -0.37 according to Fair (2002) for the same Dormer flock in an analysis based on a smaller database.

Table 3.7 Variance components and ratios (±SE) for early growth traits and lamb survival in the Elsenburg Dormer flock.

Trait	Birth weight	Weaning weight	Lamb survival*	Lamb survival**
(Co)variance components				
σ^2_a	0.09	1.35	0.002	0.002
σ^2_m	0.12	1.70	-	-
σ^2_c	0.04	1.37	0.003	0.003
σ^2_l	0.15	5.42	0.02	0.02
σ_{am}	-2.37	-	-	-
σ^2_p	0.56	22.6	0.13	0.13
Variance ratios				
h^2	0.15 ± 0.02	0.06 ± 0.02	0.02 ± 0.01	0.02 ± 0.01
m^2	0.21 ± 0.03	0.08 ± 0.02	-	-
c^2	0.08 ± 0.01	0.06 ± 0.01	0.03 ± 0.01	0.03 ± 0.01
l^2	0.28 ± 0.01	0.24 ± 0.02	0.12 ± 0.01	0.13 ± 0.01
r_{am}	-0.24 ± 0.09	-	-	-

σ^2_p: total phenotypic variance; σ^2_a: direct additive variance; σ^2_m: maternal additive variance; σ_{am}: covariance; σ^2_c: dam permanent environmental variance; h^2: direct additive; m^2: maternal additive; c^2: dam permanent environment; l^2: litter; r_{am}: genetic correlation between animal effects; *: birth weight included; **: birth weight excluded

Table 3.8 Three-trait (co)variance components and ratios (±SE) for birth weight, weaning weight and yearling weight (weight traits) of the Elsenburg Dormer flock.

Trait	Birth weight	Weaning weight	Yearling weight
h^2 on diagonal, r_g below diagonal			
Birth weight	**0.16 ± 0.03**		
Weaning weight	0.34 ± 0.11	**0.07 ± 0.02**	
Yearling weight	0.23 ± 0.14	0.83 ± 0.11	**0.17 ± 0.04**
m^2 on diagonal, r_m below diagonal			
Birth weight	**0.25 ± 0.03**		
Weaning weight	0.63 ± 0.06	**0.11 ± 0.02**	
Yearling weight	0.76 ± 0.08	0.98 ± 0.05	**0.11 ± 0.02**
σ^2_p on diagonal, r_e above and r_p below diagonal			
Birth weight	**0.504**	0.29 ± 0.02	0.31 ± 0.04
Weaning weight	0.33 ± 0.01	**22.82**	0.69 ± 0.02
Yearling weight	0.31 ± 0.02	0.76 ± 0.01	**35.46**
c^2 on diagonal, r_c below diagonal			
Birth weight	**0.06 ± 0.01**		
Weaning weight	0.54 ± 0.15	**0.04 ± 0.01**	**-**
l^2 on diagonal, r_l below diagonal			
Birth weight	**0.27 ± 0.01**		
Weaning weight	0.32 ± 0.04	**0.18 ± 0.01**	**-**

σ^2_p: total phenotypic variance component; r_p: phenotypic correlation; h^2: direct additive variance ratio; r_g: genetic correlation; m^2: maternal additive variance ratio; r_m: maternal correlation; c^2: dam permanent environment variance ratio; r_c: dam permanent environment correlation; l^2: litter variance ratio; r_l: litter correlation

Table 3.9 Summary of published variance ratios for birth weight, weaning weight and lamb survival of various sheep breeds.

Breed	h^2	m^2	c^2	Reference
Birth weight				
Romanov	0.04	0.22	0.10	Maria *et al*., 1993
Baluchi	0.17	0.10	0.08	Yazdi *et al.,* 1997
Romney	0.29	-	-	Morris *et al.,* 1996
Dormer	0.13	0.23	0.09	Van Wyk *et al*., 2003
Hampshire	0.39	0.22	0.37	Tosh & Kemp, 1994
Chios	0.18	0.19	0.17	Ligda *et al*., 2000
Dormer	0.21	0.24	0.13	Fair, 2002
Dual-purpose	0.19	-	-	Safari *et al*., 2005
Meat	0.15	-	-	Safari *et al*., 2005
Australian meat	0.16	0.14	0.11	Brown *et al*., 2016
Weaning weight				
Romanov	0.34	0.25	0.00	Maria *et al*., 1993
Coopworth	0.03 - 0.37	0.04 - 0.15	0.00 - 0.09	Lewis & Beatson, 1999
Dorper	0.20	0.10	0.08	Neser *et al*., 2001
Targhee	0.01 - 0.10	0.05 - 0.11	0.08 - 0.09	Notter & Hough, 1997
Baluchi	0.13 - 0.19	0.03	0.04 - 0.07	Yazdi *et al*., 1997
Corriedale	0.34	-	-	Brash *et al*., 1994a
Romney	0.11	-	-	Morris *et al.,* 1996
Dormer	0.13	0.21	-	Van Wyk *et al*., 1993b
Dormer	0.11	0.11	0.08	Fair, 2002
Dormer	0.07	0.08	0.07	Van Wyk *et al*., 2003
Dual-purpose	0.18	-	-	Safari *et al*., 2005
Meat	0.18	-	-	Safari *et al*., 2005
Australian meat	0.12	0.06	0.10	Brown *et al*., 2016
Lamb survival				
Dormer	0.12	-	-	Konstantinov *et al*., 1994
Dormer	0.03	-	-	Fair, 2002
Dormer*	0.02	-	-	Van Wyk *et al*., 2003
Dormer**	0.10	-	-	Van Wyk *et al*., 2003
Romney	0.01	0.02	-	Morris *et al*., 2000
Dual-purpose	0.03	-	-	Safari *et al*., 2005

CV: coefficient of variation; *: Birth weight included; **: Birth weight excluded

All wool traits were highly heritable, single-trait estimates ranging from 0.56 for clean fleece weight to 0.80 for fibre diameter (Table 3.10). Corresponding seven-trait estimates with yearling weight all exceeded 0.50 and ranged from 0.54 for clean fleece weight to 0.75 for fibre diameter (Table 3.11). The phenotypic and additive variances in Table 3.11 corresponded well with those presented in Table 3.10 for single-trait analyses. These phenotypic and additive variances were comparable to those reported by Cloete *et al*. (2002) in Western Australian Merinos and by Cloete *et al*. (2001) for SA Mutton Merinos. Fibre diameter had generally larger variance components, which can be explained by the markedly higher average fibre diameter in Dormers. The multi-trait direct heritability estimates were mostly similar to or within 0.03 of the

corresponding single-trait analyses. The exception was fibre diameter where the multi-trait analysis yielded an estimate of 0.75 in comparison with the single trait estimate that amounted to 0.80. Comparable literature estimates for dual-purpose and coarse-wool breeds ranged from 0.38 to 0.66 for clean yield, 0.29 to 0.68 for clean fleece weight and 0.43 to 0.75 for fibre diameter (Table 3.12). It is evident that the derived heritability estimates for Dormers were similar or higher than the top end of the range of values reported in the literature for fibre diameter. This generalization also applied to staple strength and the coefficient of variation of fibre diameter, which are not represented by the same number of estimates in the literature than the other wool traits which are more commonly recorded.

Table 3.10 Variance components and ratios (±SE) for yearling weight and wool traits in the Elsenburg Dormer flock.

Trait	(Co)variance components			Variance ratios	
	σ^2_a	σ^2_m	σ^2_p	h^2	m^2
Yearling weight	6.36	2.07	32.8	0.19 ± 0.06	0.06 ± 0.03
Clean yield	16.1	-	25.4	0.63 ± 0.05	-
Clean fleece weight	0.09	-	0.17	0.56 ± 0.06	-
Staple length	122	-	206.9	0.59 ± 0.06	-
Staple strength	56.3	-	95.4	0.59 ± 0.09	-
CV of fibre diameter	2.36	-	3.94	0.60 ± 0.06	-
Fibre diameter	4.54	-	5.68	0.80 ± 0.04	-

σ^2_p: total phenotypic variance; σ^2_a: direct additive variance; σ^2_m: maternal additive variance; h^2: direct heritability; m^2: maternal heritability

Table 3.11 Seven-trait variance components (in bold) as well as (co)variance ratios (±SE) for the yearling weight and yearling wool traits of the Elsenburg Dormer flock.

Trait	Correlated trait	Heritability (bold) or genetic correlation (r_g)	Environmental variance (bold) or correlation (r_e)	Phenotypic variance (bold) or correlation (r_p)
Yearling weight	**Yearling weight**	**0.20 ± 0.06**	**24.8 ± 1.50**	**31.6 ± 1.55**
	Clean yield	0.09 ± 0.14	-0.06 ± 0.06	0.00 ± 0.03
	Clean fleece weight	0.26 ± 0.14	0.32 ± 0.05*	0.27 ± 0.03*
	Staple length	0.19 ± 0.15	0.03 ± 0.06	0.08 ± 0.03*
	Staple strength	-0.08 ± 0.17	-0.05 ± 0.08	-0.06 ± 0.04
	CV of fibre diameter	-0.16 ± 0.15	-0.07 ± 0.06	-0.09 ± 0.03*
	Fibre diameter	0.13 ± 0.13	0.44 ± 0.06*	0.24 ± 0.03*
Clean yield	**Clean yield**	**0.66 ± 0.05**	**8.77 ± 1.01**	**26.0 ± 1.32**
	Clean fleece weight	0.33 ± 0.08*	0.32 ± 0.07*	0.32 ± 0.03*
	Staple length	0.43 ± 0.08*	0.06 ± 0.10	0.33 ± 0.03*
	Staple strength	0.52 ± 0.09*	0.22 ± 0.09	0.40 ± 0.04*
	CV of fibre diameter	0.26 ± 0.09*	-0.02 ± 0.08	0.15 ± 0.04*
	Fibre diameter	0.14 ± 0.08	0.19 ± 0.09*	0.15 ± 0.04*
Clean fleece weight	**Clean fleece weight**	**0.54 ± 0.06**	**0.08 ± 0.01**	**0.17 ± 0.01**
	Staple length	0.50 ± 0.08*	0.31 ± 0.06*	0.41 ± 0.03*
	Staple strength	0.34 ± 0.11*	0.05 ± 0.09	0.21 ± 0.04*
	CV of fibre diameter	0.20 ± 0.10*	-0.00 ± 0.07	0.11 ± 0.04*
	Fibre diameter	0.24 ± 0.08*	0.52 ± 0.07*	0.33 ± 0.03*
Staple length	**Staple length**	**0.59 ± 0.06**	**84.7 ± 9.00**	**206.9 ± 10.6**
	Staple strength	0.41 ± 0.10*	0.38 ± 0.09*	0.40 ± 0.04*
	CV of fibre diameter	0.05 ± 0.10	0.06 ± 0.08	0.06 ± 0.04
	Fibre diameter	0.15 ± 0.08	0.14 ± 0.09	0.15 ± 0.04*
Staple strength	**Staple strength**	**0.59 ± 0.08**	**39.6 ± 6.22**	**95.5 ± 6.56**
	CV of fibre diameter	-0.05 ± 0.12	-0.13 ± 0.10	-0.08 ± 0.04*
	Fibre diameter	0.19 ± 0.10	-0.09 ± 0.12	0.10 ± 0.04*
CV of fibre diameter	**CV of fibre diameter**	**0.58 ± 0.06**	**1.62 ± 0.17**	**3.89 ± 0.20**
	Fibre diameter	0.15 ± 0.09	-0.22 ± 0.09*	0.03 ± 0.05
Fibre diameter	**Fibre diameter**	**0.75 ± 0.04**	**4.13 ± 0.42**	**5.48 ± 0.28**

*: significant correlation; SE: standard error; CV: coefficient of variation

Table 3.12 Summary of published variance ratios for yearling live weight and yearling wool traits in the literature.

Breed	h^2	m^2 (c^2)	Reference
Yearling weight			
Dohne Merino	0.24	-	Cloete *et al*., 1998a
Targhee	0.21	-	Notter, 1998
Coopworth	0.14 - 0.45	0.02 - 0.08	Lewis & Beatson, 1999
Corriedale	0.13	-	Brash *et al*., 1994a
Baluchi	0.26 - 0.32	0.01 - 0.02	Yazdi *et al.,* 1997
Romney	0.25	-	Morris *et al.,* 1996
Dohne Merino	0.33	0.13	Cloete *et al*., 2001
SA Mutton Merino	0.45	0.12	Cloete *et al*., 2001
SA Mutton Merino	0.23	(0.02)	Cloete *et al*., 2004
Dual-purpose	0.31	-	Safari *et al*., 2005
Meat	0.30	-	Safari *et al*., 2005
Australian meat	0.24	0.04 (0.04)	Brown *et al*., 2016
Clean yield			
Corriedale	0.53	-	Brash *et al*., 1994a
Dohne Merino	0.66	-	Cloete *et al*., 1998a
Romney	0.38	-	Morris *et al.,* 1996
SA Mutton Merino	0.59	-	Cloete *et al*., 2004
Dual-purpose	0.48	-	Safari *et al*., 2005
Clean fleece weight			
Corriedale	0.29	-	Brash *et al*., 1994a
Dohne Merino	0.35	-	Cloete *et al*., 1998a
Romney	0.33	-	Morris *et al.,* 1996
Dohne Merino	0.28	0.12	Cloete *et al*., 2001
SA Mutton Merino	0.68	-	Cloete *et al*., 2001
SA Mutton Merino	0.39	(0.06)	Cloete *et al*., 2004
Dual-purpose	0.51	-	Safari *et al*., 2005
Staple length			
Romney	0.34	-	Morris *et al.,* 1996
Dual-purpose	0.48	-	Safari *et al*., 2005
Staple strength			
Dual-purpose	0.34	-	Safari *et al*., 2005
CV of fibre diameter			
Romney	0.34	-	Morris *et al.,* 1996
Dual-purpose	0.52	-	Safari *et al*., 2005
Fibre diameter			
Targhee	0.57	-	Notter, 1998
Dohne Merino	0.43	-	Cloete *et al*., 1998a
Dohne Merino	0.61	-	Cloete *et al*., 2001
SA Mutton Merino	0.75	-	Cloete *et al*., 2001
Corriedale	0.56	-	Brash *et al*., 1994a
Romney	0.47	-	Morris *et al.,* 1996
SA Mutton Merino	0.67	-	Cloete *et al*., 2004
Dual-purpose	0.57	-	Safari *et al*., 2005

CV: coefficient of variation

3.3.5 Genetic correlations among traits

Direct and maternal genetic correlations among weight traits derived from the three-trait analysis in Table 3.8 were all significant, with the exception of the direct genetic correlation between birth weight and yearling weight that did not reach a level of double the corresponding standard error. Genetic correlations of weaning weight with yearling weight were particularly high, at 0.83 at the direct and 0.98 at the maternal genetic levels. The genetic and phenotypic correlations between weaning weight and yearling weight for the Coopworth breed were very similar to those derived in the current study at respectively 0.84 and 0.61 (Brash *et al*., 1994a). The phenotypic and environmental correlations of birth weight with weaning weight and yearling weight were similar and below 0.35. The phenotypic and environmental correlations of weaning weight with yearling weight were quite similar, at 0.62 and 0.70 respectively. The genetic, maternal and phenotypic correlations among the weight traits were in accordance with those from Brown & Swan (2016) for Australian meat sheep. Dam permanent environmental and litter correlations between birth and weaning weight were lower than the corresponding maternal genetic correlations in Table 3.8. No correlations were found in the literature to compare these results. At -0.01 ± 0.18, lamb survival was not genetically correlated to birth weight. However, there were significant correlations between lamb survival at the dam permanent environmental (0.54 ± 0.14), environmental (0.19 ± 0.02) and phenotypic (0.16 ± 0.01) levels. The lack of a significant genetic correlation between these traits is consistent with results from Morris *et al*. (2000). Furthermore, it seemed as if increases in lamb birth weight would benefit lamb survival at several levels.

Genetic correlations of yearling weight with the other yearling traits were generally low and not significant (Table 3.11). Derived genetic correlations were within ranges of 0.21 to 0.43 (n = 2) for clean fleece weight and 0.01 to 0.22 for staple length (n = 2) in the literature (Table 3.13). The genetic correlation of yearling weight with clean yield (0.09) was positive in sign but not significant (i.e. smaller than twice the corresponding standard error). Two comparable literature estimates ranged from -0.10 to zero but were within the 95% confidence interval for the present estimate. The present estimate of -0.08 for the genetic correlation of yearling weight with staple strength corresponded closely with the sole literature estimate of -0.11 in Table 3.13. Corresponding estimates for the coefficient of variation of fibre diameter were -0.16 in the current study and -0.08 in Table 3.13. The present estimate of 0.13 for the genetic correlation between yearling weight and fibre diameter was just below the range of 0.15 to 0.22 in the literature. Phenotypic correlations with yearling weight amounted to 0.00 for clean yield, 0.27 for clean fleece weight, 0.08 for staple length, -0.06 for staple strength, -0.09 for coefficient of variation of fibre diameter and 0.24 for fibre diameter (Table 3.11). Corresponding literature

estimates were fairly consistent at -0.05 to 0.02, 0.35 to 0.55, 0.10 to 0.20, 0.04, -0.06 and 0.13 to 0.22 (Table 3.13).

Table 3.13 Summary of published genetic (r_g) and phenotypic (r_p) correlations among yearling weight and the yearling wool traits for various sheep breeds.

Correlated traits	r_g	r_p	Breed	References
Yearling weight x				
Clean yield	-0.10	-0.05	Romney	Morris *et al*., 1996
Clean yield	0.00	0.02	Dual-purpose	Safari *et al*., 2005
Clean fleece weight	0.43	0.55	Romney	Morris *et al*., 1996
Clean fleece weight	0.21	0.35	Dual-purpose	Safari *et al*., 2005
Staple length	0.22	0.20	Romney	Morris *et al*., 1996
Staple length	0.01	0.10	Dual-purpose	Safari *et al*., 2005
Staple strength	-0.11	0.04	Dual-purpose	Safari *et al*., 2005
CV of fibre diameter	-0.08	-0.06	Dual-purpose	Safari *et al*., 2005
Fibre diameter	0.22	0.22	Romney	Morris *et al*., 1996
Fibre diameter	0.15	0.13	Dual-purpose	Safari *et al*., 2005
Clean yield x				
Clean fleece weight	0.49	0.42	Romney	Morris *et al*., 1996
Clean fleece weight	0.24	0.30	Romney	Wuliji et al., 1998
Clean fleece weight	0.30	0.37	Corriedale	Brash *et al*., 1994a
Clean fleece weight	0.43	0.50	Corriedale	Benavides *et al*., 1998
Clean fleece weight	0.38	0.37	Dual-purpose	Safari *et al*., 2005
Staple length	0.53	0.28	Romney	Morris *et al*., 1996
Staple length	0.29	0.11	Romney	Wuliji et al., 1998
Staple length	0.25	0.19	Dual-purpose	Safari *et al*., 2005
Staple strength	0.43	0.12	Romney	Wuliji et al., 1998
Staple strength	0.35	0.15	Dual-purpose	Safari *et al*., 2005
CV of fibre diameter	-0.08	-0.13	Dual-purpose	Safari *et al*., 2005
Fibre diameter	0.31	0.20	Romney	Morris *et al*., 1996
Fibre diameter	0.19	0.14	Romney	Wuliji et al., 1998
Fibre diameter	0.10	0.09	Corriedale	Brash *et al*., 1994a
Fibre diameter	0.02	0.12	Corriedale	Benavides *et al*., 1998
Fibre diameter	0.04	0.01	Dual-purpose	Safari *et al*., 2005
Clean fleece weight x				
Staple length	0.57	0.43	Romney	Morris *et al*., 1996
Staple length	0.58	0.42	Romney	Wuliji *et al*., 1998
Staple strength	0.20	-0.04	Dual-purpose	Safari *et al*., 2005
Staple strength	0.53	0.30	Romney	Wuliji *et al*., 1998
CV of fibre diameter	0.19	-0.04	Dual-purpose	Safari *et al*., 2005

Fibre diameter	0.57	0.41	Romney	Morris *et al*., 1996
Fibre diameter	0.55	0.37	Romney	Wuliji *et al*., 1998
Fibre diameter	0.19	0.19	Dual-purpose	Safari *et al*., 2005
Fibre diameter	0.29	0.39	Corriedale	Brash *et al*., 1994a
Fibre diameter	0.34	0.45	Corriedale	Benavides *et al*., 1998
Staple length x				
Staple strength	0.05	0.07	Dual-purpose	Safari *et al*., 2005
Staple strength	0.44	0.34	Romney	Wuliji *et al*., 1998
CV of fibre diameter	-0.06	-0.12	Dual-purpose	Safari *et al*., 2005
Fibre diameter	0.37	0.35	Romney	Wuliji *et al*., 1998
Fibre diameter	0.55	0.37	Romney	Morris *et al*., 1996
Staple strength x				
CV of fibre diameter	-0.52	-0.38	Dual-purpose	Safari *et al*., 2005
Fibre diameter	0.37	0.23	Dual-purpose	Safari *et al*., 2005
Fibre diameter	0.61	0.32	Romney	Wuliji *et al*., 1998
CV of fibre diameter x				
Fibre diameter	0.11	0.19	Romney	Morris *et al*., 1996
Fibre diameter	-0.10	-0.09	Dual-purpose	Safari *et al*., 2005

CV: coefficient of variation

Clean yield had low to moderate genetic correlations with the other traits, ranging from 0.14 with fibre diameter to 0.52 with staple strength (Table 3.11). All of the genetic correlations with clean yield and wool traits were significant except for the unfavourable correlation with fibre diameter. Genetic correlations with clean yield were within the literature range of 0.24 to 0.49 (n = 5) for clean fleece weight, 0.25 to 0.53 (n = 3) for staple length and 0.02 to 0.31 (n = 5) for fibre diameter (Table 3.13). The genetic correlation of 0.52 between clean yield and staple strength was slightly above the literature range of 0.35 to 0.43, based on two estimates. The positive genetic correlation of 0.26 between clean yield and coefficient of variation of fibre diameter was opposite in sign and higher in magnitude than the only other estimate of -0.08 in the literature (Table 3.13). Phenotypic correlations involving clean yield and other wool traits were also consistent with literature ranges for clean fleece weight, staple length and fibre diameter, but generally higher for staple strength and coefficient of variation of fibre diameter.

Clean fleece weight was significantly correlated to all the other wool traits on the genetic level, estimates ranging from 0.20 for coefficient of variation of fibre diameter to 0.50 for staple length (Table 3.11). Derived estimates were within ranges of 0.20 to 0.52 (n = 2) for staple strength and 0.19 to 0.57 (n = 5) for fibre diameter (Table 3.13). The only correlation with coefficient of variation of` fibre diameter (0.19) in the literature compared well to the estimate derived in the current study. The present genetic correlation of 0.50 between clean fleece weight and staple length were somewhat below the range of 0.57 to 0.58 based on two

literature estimates. The derived phenotypic correlations in Table 3.11 were all close to or within the corresponding ranges of literature estimates (Table 3.13) except for the correlation with coefficient of variation of fibre diameter which amounted to 0.11 in the current study while the derived estimate in Table 3.13 amounted to -0.04.

Staple length was significantly correlated with staple strength on a genetic level (Table 3.11). The derived estimate of 0.41 was on the higher end of the comparable range of 0.05 to 0.44 in the literature (Table 3.13). However, the present estimate of 0.15 for the genetic correlation of staple length with fibre diameter was appreciably lower than the comparable range of 0.37 to 0.55 in the literature. The genetic correlation of 0.05 for staple length with the coefficient of variation of fibre diameter did not differ from zero. The only other value in the literature to compare this estimate to was the value of -0.06 derived from the literature by Safari *et al*. (2005; Table 3.13). The phenotypic correlation of staple length with staple strength (0.40) was higher than the corresponding range of 0.07 to 0.34 in the literature. In contrast, the phenotypic correlation of 0.15 between staple length and fibre diameter was markedly smaller than the range of 0.37 to 0.55 in the literature (Table 3.13).

The genetic correlation of -0.05 for staple strength with coefficient of variation of fibre diameter was not significant (Table 3.11). The mean value for this genetic correlation derived by Safari *et al*. (2005) amounted to -0.52 which is substantially higher than the present estimate. The latter favourable genetic correlation led Matebesi-Ranthimo *et al*. (2017) to propose that coefficient of variation of fibre diameter might serve as a usable proxy for the more expensive and cumbersome staple strength analysis. However, this is clearly not a strategy that could be considered for Dormers. The genetic correlation of 0.19 for staple strength with fibre diameter was substantially smaller in magnitude than the range of 0.37 to 0.61 based on two literature estimates (Table 3.13). Phenotypic correlations of staple strength with coefficient of variation of fibre diameter and fibre diameter in the literature were accordingly higher than the present estimates in Table 3.11.

The genetic correlation of coefficient of variation of fibre diameter with fibre diameter was not significant at 0.15 (Table 3.11). This value was somewhat above the range of -0.10 to 0.11 reported in the literature (Table 3.13) but the latter range was within the 95% confidence interval. The phenotypic correlation between the coefficient of variation of fibre diameter and fibre diameter of 0.03 was within the range of -0.09 to 0.19 reported in the literature.

3.3.6 Genetic trends

Genetic trends for weight traits were derived for the period from 1943 to 2019. Birth weight showed a small increase amounting to 0.12% p.a. of the phenotypic mean both for direct and maternal breeding values (Table 3.14). The increase in direct breeding values for weaning weight was somewhat faster at 0.16% p.a. of the phenotypic mean, but maternal breeding values increased at a slower rate of 0.09% p.a. of the phenotypic mean. Figure 3.5 shows a scatterplot of the individual direct and maternal breeding values for weaning weight as well as line graphs depicting the mean breeding values to reflect the direct and maternal genetic trends. The faster direct response in weaning weight that was achieved is quite evident in the information supplied in Table 3.14 and Figure 3.5.

The genetic trends for the yearling traits were calculated over a much shorter period as data were only available since 2007. It was not attempted to construct a genetic trend for staple strength, since data were only available in some years. The genetic change in yearling weight was by far the fastest of all traits, amounting to 0.45% p.a. of the overall phenotypic mean (Table 3.14 and Figure 3.6). It is assumed that the significant slopes of genetic trends involving some of the wool traits are spurious, since no direct selection has been applied to any of these traits. However, there was an indication that the breeding values for clean fleece weight, clean yield and the coefficient of variation of fibre diameter declined at between 0.15 and 0.29% p.a. The genetic trend for fibre diameter indicated that the wool of the Elsenburg Dormer flock became coarser at 0.23% p.a.

Table 3.14 The intercept and slope of regression equations depicting genetic trends in the units of measurement, as well as expressed as a percentage of the overall phenotypic mean of the respective traits as indication of change in the genetic merit, expressed relative to the overall mean.

Trait	Intercept ± SE	Coefficient (slope) ± SE	Genetic merit (%)
BW_{direct} (kg)	-0.234 ± 0.00467	0.00387 ± 0.0000556	0.0985
$BW_{maternal}$ (kg)	-0.402 ± 0.00589	0.00358 ± 0.0000702	0.0911
WW_{direct} (kg)	-4.06 ± 0.0205	0.0473 ± 0.000244	0.163
$WW_{maternal}$ (kg)	-2.76 ± 0.0178	0.0262 ± 0.000262	0.09
YW_{direct} (kg)	-23.9 ± 1.28	0.234 ± 0.0114	0.455
CY (%)	18.6 ± 2.17	-0.161 ± 0.0193	-0.218
CFW (kg)	0.379 ± 0.124	-0.00314 ± 0.00110	-0.150
SL (mm)	-0.826 ± 5.61	0.0146 ± 0.0499	0.0138
CVFD (%)	5.93 ± 0.771	-0.0531 ± 0.00686	-0.290
FD (µm)	-8.12 ± 1.15	0.0671 ± 0.0103	0.233

BW: birth weight; WW: weaning weight; YW: yearling weight; CY: clean yield; CFW: clean fleece weight; SL: staple length; CVFD: coefficient of variation of fibre diameter; FD: fibre diameter; direct: direct genetic trend; maternal: maternal genetic trend

Table 3.15 Genetic trends from the literature for early ovine weights. Direct and maternal genetic progress explained as kg per annum and the percentage in brackets.

Direct genetic progress (kg)	R^2 direct	Maternal genetic progress (kg)	R^2 maternal	Breed	Reference
Birth weight (kg)					
-0.002 (-0.07)*	0.09	-	-	Madras Red[a]	Balasubramanyam *et al*., 2012
0.002 (0.04)	0.73	0.002 (0.04)	0.84	Moghani[a]	Hossein-Zadeh, 2012
0.002 (0.06)	0.44	0.003 (0.09)	0.74	Kermani[b]	Mokhtari & Rashidi, 2010
0.006 (0.20)	-	-	-	Tropical fat tailed[c]	Negussie *et al*., 2002
0.006 (0.16)	-	-	-	Dorper[c]	Kariuki *et al.,* 2010
0.009 (0.02)	0.57	0.007 (0.17)	0.73	Makooei[b]	Mohammadi *et al*., 2012
-0.002 (-0.06)	0.42	-	-	Dormer[b]	Zishiri *et al*., 2010
0.001 (0.03)	-	-	-	Ile de France[b]	Zishiri *et al*., 2010
0.02	-	-	-	Kurdish[b]	Rashidi & Akheshi, 2007
0.002	-	0.005	-	Zandi[b]	Mohammadi & Shahrebabak, 2011
0.06 (2.00)*	-	-	-	Malpura[b]	Arora *et al.,* 2010
0.002 (0.05)	0.78	0.02 (0.54)	0.95	Arman[b]	Farokhad *et al*., 2011
Weaning weight (kg)					
0.07 (0.71)	0.41	-	-	Madras Red[a]	Balasubramanyam *et al*., 2012
0.07 (0.30)	0.85	0.05 (0.21)	0.80	Moghani[a]	Hossein-Zadeh, 2012
0.13 (0.63)	0.81	-	-	Kermani[b]	Mokhtari & Rashidi, 2010
0.04 (0.20)	-	-	-	Tropical fat tailed[c]	Negussie *et al*., 2002
0.10 (0.50)	-	-	-	Dorper[c]	Kariuki *et al.,* 2010
0.07 (0.31)	0.78	-	-	Makooei[b]	Mohammadi *et al*., 2012
0.04 (0.12)	-	-	-	Dormer[b]	Zishiri *et al*., 2010
0.34 (1.21)	-	-	-	Ile de France[b]	Zishiri *et al*., 2010
0.04	-	-	-	Ossimi[b]	Shaat *et al*., 2004
0.09	-	-	-	Rahmani[b]	Shaat *et al*., 2004
0.13	-	-	-	Kurdish[b]	Rashidi & Akheshi, 2007
0.10	-	-	-	Zandi[b]	Mohammadi & Shahrebabak, 2011
0.007 (0.03)	0.79	0.007 (0.03)	0.94	Arman[b]	Farokhad *et al*., 2011
Post weaning weight (kg)					
0.12 (0.57)	0.57	-	-	Madras Red[a]	Balasubramanyam *et al*., 2012
0.11 (0.28)	0.76	0.01 (0.03)	0.72	Moghani[a]	Hossein-Zadeh, 2012
0.16 (0.67)	0.71	-	-	Kermani[b]	Mokhtari & Rashidi, 2010
0.09 (0.30)	-	-	-	Tropical fat tailed[c]	Negussie *et al*., 2002
0.16 (0.44)	-	-		Dorper[c]	Kariuki *et al.,* 2010
0.05 (0.12)	0.88	-	-	Makooei[b]	Mohammadi *et al*., 2012
0.46 (1.69)	-	-	-	Malpura[b]	Arora *et al.,* 2010
0.04	-	-	-	Zandi[b]	Mohammadi & Shahrebabak, 2011
0.15 (0.26)	0.72	-	-	Dohne Merino[e]	Cloete *et al*., 1998a
0.63 (1.20)	0.94	-	-	Merino[d]	Olivier *et al*., 1995

[a]: selected for body weight; [b]: undefined; [c]: unselected; [d]: selected for clean fleece weight with limitations on fibre diameter; [e]: selected for increase body weight, decrease fibre diameter and maintain clean fleece weight; *: not significant; R^2: coefficient of determination

The annual direct genetic change of birth weight was derived as 0.099% in Table 3.14. Estimates in other studies reported a range of values from -0.07 to 2.00% (n = 12; Table 3.15). The direct genetic change of birth weight from the current study fitted within this range. The maternal genetic change of the current study was 0.09% (Table 3.15). The estimates from literature in Table 3.15 ranged from 0.04 to 0.54% per annum (n = 5). The maternal genetic change fitted well within this range although it was evidently at the lower end of the range.

The direct genetic change for weaning weight amounted to 0.16% (Table 3.14). Estimates from the literature in Table 3.15 mostly depicted faster annual gain than in the current study and ranged from 0.03 to 1.21% per annum (n = 13). The maternal genetic change for weaning weight was calculated at 0.09% (Table 3.14). The annual genetic gain from earlier literature were derived from only two estimates (0.03 to 0.21%) (Table 3.15). The maternal genetic change for weaning weight estimated during this study was within this range.

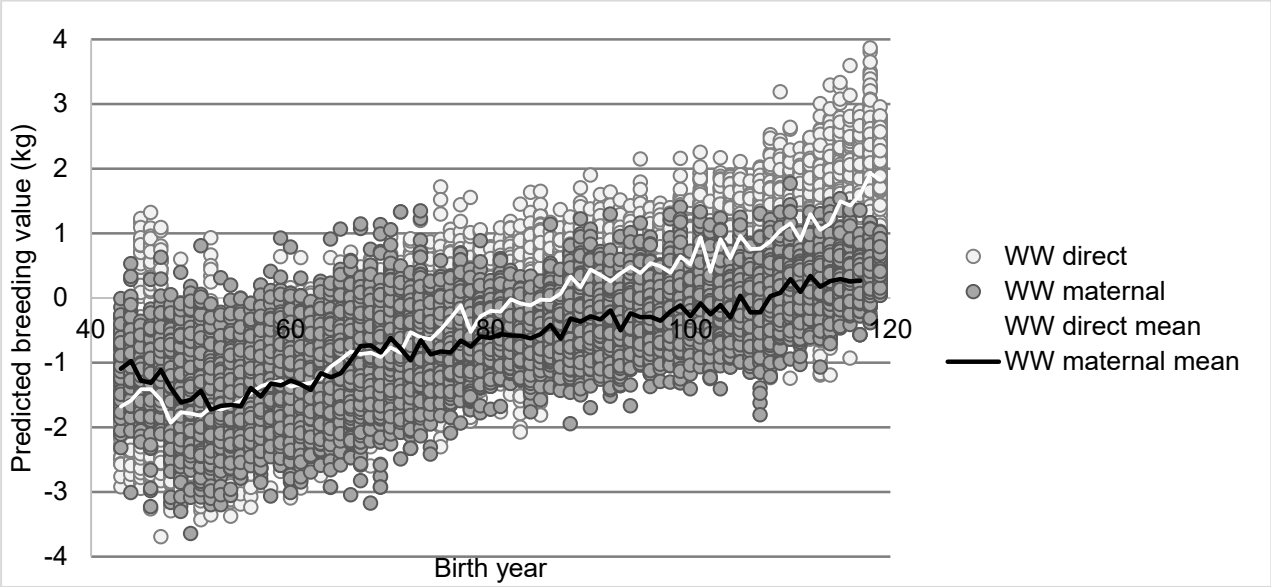

Figure 3.5 Scatter-plot depicting direct and maternal predicted breeding values for weaning weight (WW) from 1943 to 2019 as well as line graphs indicating the genetic trend based on year averages for predicted breeding values.

The annual direct genetic change for yearling weight in the current study was derived at 0.46% (Table 3.14). Most previous studies (Table 3.15) found higher genetic gains for yearling weight than the current study, with a range of 0.12 to 1.69% per annum. The annual genetic gain of 1.69% for Malpura sheep (Arora *et al.,* 2010) and of 1.20% for Merino sheep (Olivier *et al*., 1995) marked the extremes of this range. It should be noted that the latter study involved selection for a breeding objective that included an increase in body weight, while simultaneously reducing fibre diameter and maintaining clean fleece weight. It should, however, be noted that the heritability of hogget live weight in the resource population used by Olivier *et al*. (1995) was

almost double that of the value derived in the present study at 0.38, thus allowing a faster rate of gain to be achieved.

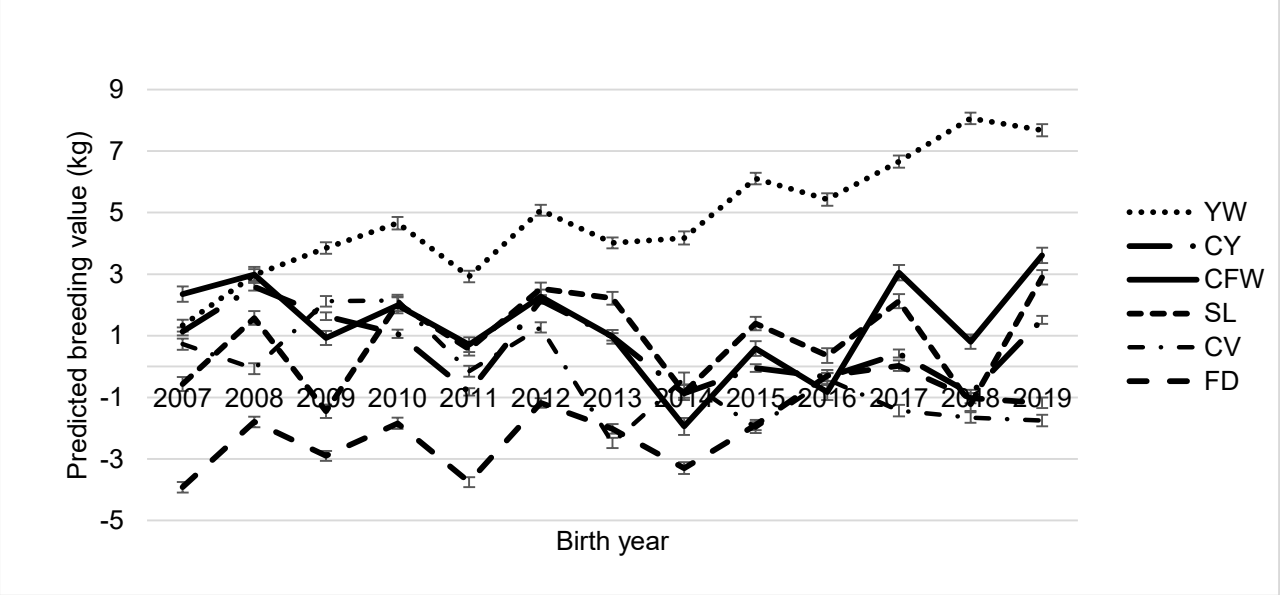

Figure 3.6 Line graphs indicating genetic trends for yearling weight (YW), clean yield (CY), clean fleece weight (CFW), staple length (SL), coefficient of variation of fibre diameter (CV) and fibre diameter (FD) from 2007 to 2019. The vertical lines about means denote standard errors.

Wool traits would be of lesser importance in a terminal sire breed like the Dormer. The presumed spurious changes that were noticed in these traits were therefore not compared to literature involving directional selection for wool characteristics in wool breeds.

3.4 Conclusion

All traits analysed in the Elsenburg Dormer flock were variable and heritable. Selection should thus result in worthwhile genetic progress if desired. It was notable that the heritability estimates for yearling wool traits were generally higher than comparable estimates in the literature. This result may stem from a lack of selection for wool traits in the flock (and probably the breed in general), resulting in a largely unselected genetic resource and ample genetic and phenotypic variation to be exploited. Genetic correlations of yearling weight with wool traits appear to be generally smaller in magnitude compared to results obtained from the literature. Further research should study whether this is characteristic of Dormers in general or if it is simply a reflection of the relative small number of records processed for wool traits. More research on wool traits in Dormers is clearly needed.

Considering the presence of usable levels of genetic variation, genetic change that accrued was disappointingly slow with the genetic change of 0.45% per annum for yearling weight being the best selection response that could be achieved. This rate of gain was still relatively slow compared to achievable gains of at least 1% per annum that is usually expected

from genetic selection. This could be due to the emphasis placed on subjective conformation traits during selection even before selection on performance. The impact of selection for subjective conformation traits on genetic gains in the flock is a future study field worthy of pursuing. Further studies on the flock should also include other traits of economic importance such as reproduction.

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Chapter 4
Responses to selection for direct and/or maternal breeding values for growth traits of Elsenburg Dormer sheep

Abstract

This study investigated the response to selection for direct and/or maternal breeding values for weaning weight in the Elsenburg Dormer resource flock. The flock was divided in three groups during 2012. Subsequent selection was based on direct, maternal and a combination of direct and maternal breeding values for weaning weight (WW) up to 2019. Predicted breeding values from the analyses in Chapter 3 were used to derive genetic trends for the weight traits in each of these lines. Expressed relative to overall phenotypic means, direct genetic trends in the line selected from direct breeding values for WW amounted to 0.07% for birth weight, 0.79% for WW and 1.01% for yearling weight. Corresponding genetic trends in the line selected for maternal breeding values for WW amounted to respectively -0.51%, 0.17% and 0.27%. Corresponding genetic trends in the line selected for a combination of direct and maternal breeding values were respectively -0.20%, 0.41% and 0.58%. Maternal genetic trends were smaller in magnitude and characterized by a poor fit in the two lines where maternal breeding values were considered during selection. It was evident that selection for direct breeding values for WW resulted in worthwhile genetic responses in weight traits, as was expected. However, responses in those lines selected for higher maternal breeding values were disappointing. Further studies are required to elucidate these results.

4.1 Introduction

Livestock contributes about half of South Africa's gross domestic agricultural production (Abstract of Agricultural Statistics, 2019). The contribution of small stock to the national livestock production is relatively small at approximately 8% (Cloete & Olivier, 2010). However, the industry is of paramount importance because of the ability of sheep and goats to adapt to marginal resources. It is well known that large parts of South Africa have limited cropping potential and are only suitable for extensive livestock production. This role is mainly fulfilled by extensive sheep enterprises in the dry western parts of the country. Sheep are also well adapted to supplement the more capital- and labour-intensive grain industries by using crop residues as a source of sustenance.

The Dormer breed originated in the 1940’s when Dorset Horn rams were mated to German Merino ewes at the Elsenburg Research Farm in the Western Cape. The objective was

to develop a composite white-wool terminal sire breed for crossbreeding on woolled breeds (Van der Merwe, 1976; De Villiers & Cloete, 1984). The Dormer breed proved to be successful in this role, producing slaughter lambs with a good meat quality (Erasmus *et al*., 1983; Cloete *et al*., 2004a; 2008). The analysis of data from the flock during its almost 80-year existence led to several studies being written up as MSc and PhD theses (Van der Merwe, 1976; Kritzinger, 1982; Van Wyk, 1992; Fair, 2002). The Dormer is the largest terminal sire breed in South Africa, as suggested by the number of records included in the National Livestock Improvement Scheme database (Zishiri, 2009, Cloete & Olivier, 2010).

Breeding objectives in terminal sire breeds usually include fast early growth as a direct trait as well as a favourable carcass quality. Aspects such as sexual dimorphism are also important in terminal crossbreeding enterprises (Roux, 1992). Until 2012, selection in the Dormer breed was more for a dual-purpose breed, with emphasis also on reproduction and conformation. Van Wyk *et al*. (1993; 2003) and Fair (2002) reported relatively low levels of direct genetic variation in the weaning weight of the Elsenburg Dormer flock. However, maternal genetic variation, as well as a strong negative correlation between direct and maternal breeding values for birth weight, were also found. By nature, selection decisions are complicated by such correlations. If the selection policy of the breed is to produce terminal crossbreeding sires for commercial use on Merino-type ewes, then not much emphasis should be placed on aspects such as maternal breeding values for early growth and ewe reproduction. Attempts can only be made to maintain the already acceptable reproduction rate in the breed under such conditions. Genetic parameters for reproduction have been estimated in the Elsenburg Dormer resource flock (Fair, 2002; Van Wyk *et al*., 2003). These parameters were in line with estimates in Merinos, where significant genetic progress has been attained (Cloete *et al*., 2004b). Unfortunately, no genetic studies have yet been performed on the genetic relationship between growth and reproduction in the Dormer breed, making it only possible to speculate on possible adverse effects of selection for growth on reproduction. However, this information is crucial for informed decision-making about a future selection policy for the Elsenburg flock and the Dormer breed in general.

There are also no genetic parameters for post-weaning growth in the Elsenburg Dormer flock apart from those in Chapter 3. Zishiri *et al*. (2014) reported a heritability estimate of 0.37 for post-weaning weight in the national Dormer flock, but with a negative direct-maternal genetic correlation approaching unity. It is assumed, based on this result for Dormers, as well as age trends in genetic variation in Afrinos (Snyman *et al*., 1995) that a higher heritability is expected than for weaning weight, while maternal genetic variation is likely to decline. Based on the parameters in Chapter 3, it could be suggested that genetic progress in yearling weight might

be easy to realize. Van der Merwe (1976) also indicated that selection response in weaning weight would theoretically be easier to achieve by indirect selection for yearling weight.

Against this background, the aim of this study was to investigate the direct and correlated responses to selection for direct and/or maternal breeding values for weaning weight in Elsenburg Dormer sheep.

4.2 Materials and Methods

4.2.1 Animal resources, the environment and management

The data were obtained from the Dormer resource flock that was maintained at Elsenburg Research Farm close to Stellenbosch in the Western Cape as detailed in Chapter 3. Briefly, Elsenburg is situated in a winter rainfall region with an average annual rainfall of 642 mm, most of which is expected between April and September. The farm has an altitude of 177 m above sea level with GPS coordinates of 33º 51’ S, 18º 30’ E. Over time the flock consisted of between 120 and 180 breeding ewes. The day-to-day management of the flock is described in Chapter 3. It is, however, important to note that this part of the study only involved the period from 2013 to 2019. It should be noted that management practices changed over this period in line with challenges posed by drought and the available infrastructure but that care was taken to ensure a fairly uniform treatment of all cohorts produced during the period used for this study.

4.2.2 Data recorded and selection practices implemented

Data for this study were recorded from 2013 to 2018. Lambs were identified together with their dams and a birth weight was recorded within 24 hours of birth as described in Chapter 3. Weaning and yearling weights were recorded at approximately 102 and 365 days of age, respectively. The lambs were maintained until visual assessment and selection at yearling age.

The available adult and replacement ewes for mating in the spring of 2012 were randomly allocated to one of three genetic selection lines of 50 to 70 breeding ewes as described below. Ram and ewe replacements from the 2014 progeny group and onwards were then selected within selection lines. The selection lines and replacement policy were as follows:

- Weaning Weight Direct: The replacement rams and ewes with the highest direct breeding values for weaning weight were selected. The provision was that the selected animals should also be average or below average for their maternal breeding values for weaning weight.

- Weaning Weight Maternal: The replacement rams and ewes with the highest maternal breeding values for weaning weight were selected. The provision was that the selected animals should also be average or below average for their direct breeding values for weaning weight.
- Weaning Weight Both (Direct and Maternal): The replacement rams and ewes with above average direct as well as maternal breeding values for weaning weight were preferred as breeding stock for the next generation.

These lines were maintained as separate genetic lines within a single breeding flock. All ewe replacements as well as the bulk of ram replacements were obtained from within lines, although externally sourced rams were also used occasionally to ensure that inbreeding was kept at manageable levels. The relatively small size of the selection lines as well as the small number of rams used annually required special attention to the relatedness of individuals within selection lines.

4.2.3 Statistical analysis

The data being analysed in this study stemmed from multi-trait animal solutions reflecting direct and maternal breeding values for birth and weaning weight as well as direct breeding values for yearling weight. These breeding values were from the three-trait analysis on birth, weaning and yearling weight that was conducted in Chapter 3. Data so obtained had to be corrected for genetic change that accrued before 2014 in the respective selection lines. For this purpose, within selection line means for direct and maternal within-trait breeding values in 2013 were subtracted from individual breeding values in 2013 and in subsequent years. This procedure reset selection line means for all traits and the genetic level to zero for the respective 2013 cohorts. Individual breeding values then were regressed on birth year within the three selection lines to depict genetic change in response to selection per annum. All the regressions were forced through the origin (the 2013 progeny group that was not selected as described above). Although the reported regression equations depicting genetic trends were based on individual breeding values, a scatter-plot based on individual breeding values became quite messy. Therefore, the graphs shown are based on the averaged predicted breeding values (±SE) for each year within selection lines.

Ethical clearance for the study was obtained from Departmental ethical committee for research on animals (DECRA) of the Western Cape, reference numbers R12/55 and S12/56.

4.3 Results

4.3.1 Genetic trends in birth weight

Table 4.1 illustrates regression equations of individual predicted breeding values on year of birth for weight traits from 2013 to 2018 for the three selection lines. Selection in the Weaning Weight Direct selection line did not result in any change with time in the obtained direct breeding values for birth weight (Table 4.1 and Figure 4.1). In contrast, direct birth weight breeding values for the selected on maternal breeding values declined (when expressed to the overall mean for each trait in the data) at 0.51% per annum in the Weaning Weight Maternal line and 0.20% per annum in the Weaning Weight Both line. The regression in Table 4.1 strongly suggested that maternal breeding values for birth weight increased with time in the Weaning Weight Direct line. However, closer scrutiny of the trend in Figure 4.2 rather suggested that the 2014 progeny group in this line had a markedly higher averaged breeding value than the 2013 progeny group, with very little subsequent change. Maternal breeding values for birth weight in the Weaning Weight Maternal line also inclined at 0.18% of the overall mean, while no obvious change was observed in the Weaning Weight Both selection line (Table 4.1 and Figure 4.2).

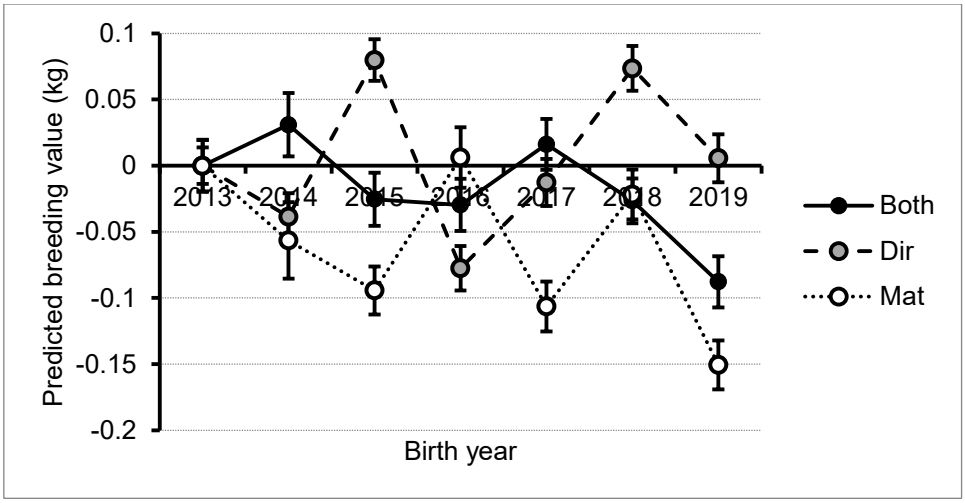

Figure 4.1 Mean predicted breeding values for birth weight direct from 2013 to 2019 for the respective selection lines, namely Weaning Weight Direct (Dir), Weaning Weight Maternal (Mat) and Weaning Weight Both (Both). Vertical lines about means denote standard errors.

Table 4.1 Regression equations (±SE) of individual predicted breeding values on year of birth for weight traits from 2013 to 2018 for the three selection lines.

Trait and selection line	Regression (*b* ± SE)	*R*	r^2
Birth weight direct			
Weaning Weight Direct	0.003 ± 0.002	0.06	0.004
Weaning Weight Maternal	-0.02 ± 0.002*	0.49	0.24
Weaning Weight Both[a]	-0.008 ± 0.002*	0.25	0.06
Birth weight maternal			
Weaning Weight Direct	0.03 ± 0.002*	0.68	0.46
Weaning Weight Maternal	0.007 ± 0.001*	0.25	0.06
Weaning Weight Both[a]	0.003 ± 0.002	0.09	0.009
Weaning weight direct			
Weaning Weight Direct	0.23 ± 0.01*	0.74	0.54
Weaning Weight Maternal	0.05 ± 0.01*	0.26	0.07
Weaning Weight Both[a]	0.12 ± 0.009*	0.59	0.34
Weaning weight maternal			
Weaning Weight Direct	0.09 ± 0.006*	0.60	0.36
Weaning Weight Maternal	0.01 ± 0.004*	0.13	0.02
Weaning Weight Both[a]	-0.03 ± 0.004*	0.30	0.09
Yearling weight direct			
Weaning Weight Direct	0.52 ± 0.02*	0.71	0.50
Weaning Weight Maternal	0.14 ± 0.02*	0.30	0.09
Weaning Weight Both[a]	0.30 ± 0.02*	0.61	0.37

Regressions were forced through the origin in all instances
B: regression coefficient; *R*: correlation coefficient; r^2: proportion of the variance in predicted breeding values that could be attributed to its linear regression on birth year; [a]: direct and maternal selection line; *: significant at P < 0.05

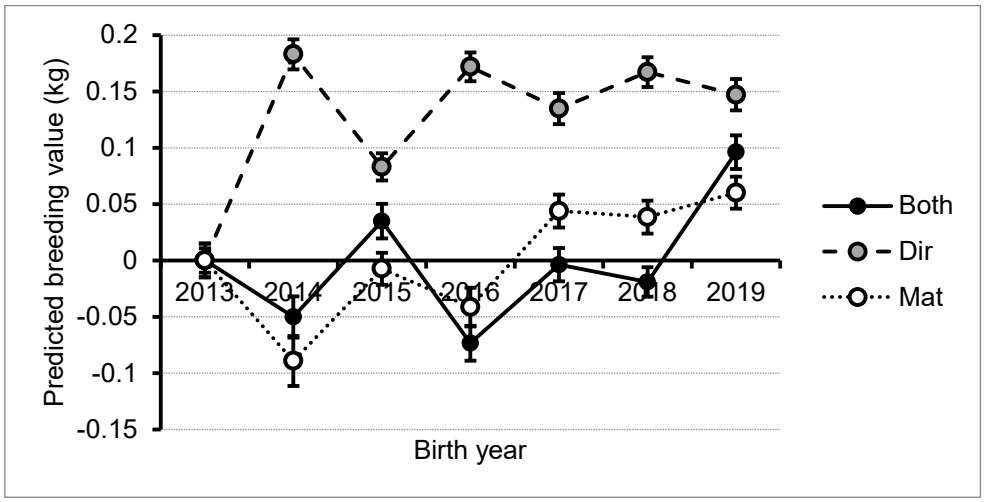

Figure 4.2 Mean predicted breeding values for birth weight maternal from 2013 to 2019 for the respective selection lines, namely Weaning Weight Direct (Dir), Weaning Weight Maternal (Mat) and Weaning Weight Both (Both). Vertical lines about means denote standard errors.

4.3.2 Genetic trends in weaning weight

Positive genetic change in direct breeding values for weaning weight was quite evident for the Weaning Weight Direct and the Weaning Weight Both selection lines, amounting to respectively 0.79% and 0.41% of the overall mean for weaning weight (Table 4.1 and Figure 4.3). Although the slope for the Weaning Weight Maternal selection line was also positive, it might have been associated with a fairly high averaged breeding value in this selection line for 2018 (Figure 4.3). Apart from this, there appear to be limited evidence of mentionable genetic change for weaning weight in the Weaning Weight Maternal selection line.

Means for the maternal genetic trend in weaning weight for the Weaning Weight Direct selection line followed the same pattern as those of the maternal genetic trend for birth weight (Figures 4.2 and 4.4). It is notable that, although there was some evidence for positive maternal genetic change in weaning weight in the Weaning Weight Maternal selection line, it amounted to only 0.03% per annum. Contrary to expectations, the maternal genetic trend for the Weaning Weight Both selection line showed a decline instead of an incline. The possible cause of this result is not evident and requires further research.

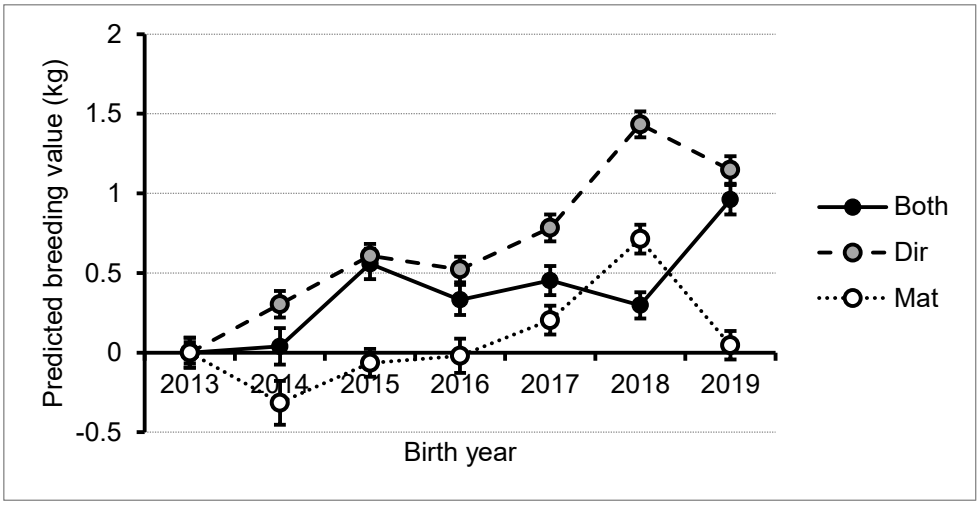

Figure 4.3 Mean predicted breeding values for weaning weight direct from 2013 to 2019 for the respective selection lines, namely Weaning Weight Direct (Dir), Weaning Weight Maternal (Mat) and Weaning Weight Both (Both). Vertical lines about means denote standard errors.

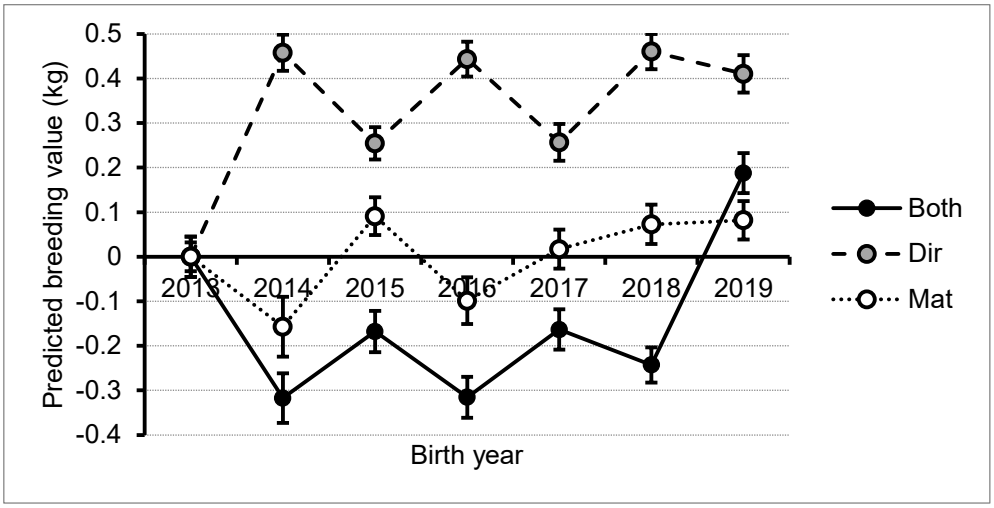

Figure 4.4 Mean predicted breeding values for weaning weight maternal from 2013 to 2019 for the respective selection lines, namely Weaning Weight Direct (Dir), Weaning Weight Maternal (Mat) and Weaning Weight Both (Both). Vertical lines about means denote standard errors.

4.3.3 Genetic trends in yearling weight

The realised direct genetic gain in yearling weight for the Weaning Weight Direct line was positive and amounted to 1.01% per annum (Table 4.1 and Figure 4.5). This result probably stems from the generally higher heritability of yearling weight compared to weaning weight as well as the near unity genetic correlation between the traits (Chapter 3). Positive direct genetic change was also evident for the Weaning Weight Both selection line (0.58% per annum) and the Weaning Weight Maternal selection line (0.27% per annum). It is thus clear that, although it was not the objective of the study, selection for maternal breeding values resulted in unexpected direct genetic gains in the latter selection line. The contribution of the unexpectedly high average direct genetic breeding value in this line for 2018 needs further study (Figure 4.5). Since the study was conducted over a relatively short timespan, year-to-year variation could still be appreciable and it was decided to accept all values as they were.

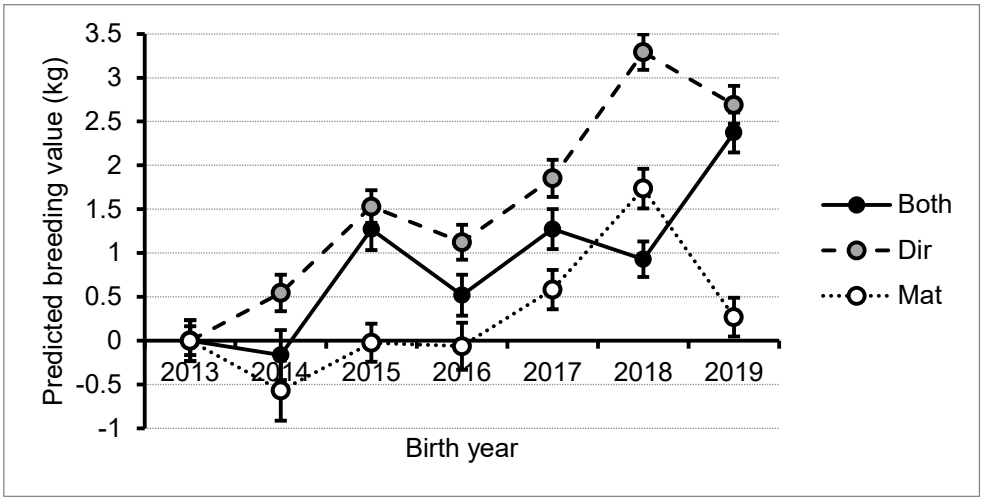

Figure 4.5 Mean predicted breeding values for yearling weight direct from 2013 to 2019 for the respective selection lines, namely Weaning Weight Direct (Dir), Weaning Weight Maternal (Mat) and Weaning Weight Both (Both). Vertical lines about means denote standard errors.

There were overall direct genetic improvements in weaning weight and yearling weight in all three selection lines, despite fluctuations noticed in the graphs. Birth weight was not directly selected for in this study as bigger lambs may cause dystocia in the future (Hickson *et al*., 2006). There is therefore a need to monitor the maternal genetic change in the Weaning Weight Direct selection line.

4.4 Discussion

In addition to understanding the impact of selection on direct and maternal breeding values in meat sheep, selection decisions for replacement animals were also made on the basis of conformation and breed standards together with growth. Periodic evaluation of genetic gain is essential as trends in genetic improvement help to decide how effectively genetic selection was done (Negussie *et al*., 2002). The evaluation of the genetic trends in this particular Dormer flock gives a good indication of the direction in terms of breeding as well as the rate of genetic improvement that accrued since the application of the breeding programme (Bosso *et al.,* 2007).

The direct genetic trends for birth weight from the literature in Table 4.2 ranged from -0.6% and -0.7% for Dormer and Madras sheep (Zishiri *et al*., 2010; Balasubramanyam *et al*., 2012) to 0.20% for Tropical fat tailed sheep (Negussie *et al*., 2002). The latter result agreed in magnitude with the Weaning Weight Both selection line but differed in sign, as direct breeding values for birth weight in the current study declined by 0.20% (Table 4.1).

Table 4.2 Genetic trends from the literature for ovine birth and weaning weights. Direct and maternal genetic progress explained as kg per annum with the percentage in brackets.

Direct genetic progress (kg)	R^2 direct	Maternal genetic progress (kg)	R^2 maternal	Breed	Reference
Birth weight (kg)					
-0.002 (-0.07)*	0.09	-	-	Madras Red[a]	Balasubramanyam *et al*., 2012
0.002 (0.04)	0.73	0.002 (0.04)	0.84	Moghani[a]	Hossein-Zadeh, 2012
0.002 (0.06)	0.44	0.003 (0.09)	0.74	Kermani[b]	Mokhtari & Rashidi, 2010
0.006 (0.20)	-	-	-	Tropical fat tailed[c]	Negussie *et al*., 2002
0.006 (0.16)	-	-	-	Dorper[c]	Kariuki *et al.,* 2010
0.009 (0.02)	0.57	0.007 (0.17)	0.73	Makooei[b]	Mohammadi *et al*., 2012
-0.002 (-0.06)	0.42	-	-	Dormer[b]	Zishiri *et al*., 2010
0.001 (0.03)	-	-	-	Ile de France[b]	Zishiri *et al*., 2010
0.02	-	-	-	Kurdish[b]	Rashidi & Akheshi, 2007
0.002	-	0.005	-	Zandi[b]	Mohammadi & Shahrebabak, 2011
0.06 (2.00)*	-	-	-	Malpura[b]	Arora *et al.,* 2010
0.002 (0.05)	0.78	0.02 (0.54)	0.95	Arman[b]	Farokhad *et al*., 2011
Weaning weight (kg)					
0.07 (0.71)	0.41	-	-	Madras Red[a]	Balasubramanyam *et al*., 2012
0.07 (0.30)	0.85	0.05 (0.21)	0.80	Moghani[a]	Hossein-Zadeh, 2012
0.13 (0.63)	0.81	-	-	Kermani[b]	Mokhtari & Rashidi, 2010
0.04 (0.20)	-	-	-	Tropical fat tailed[c]	Negussie *et al*., 2002
0.10 (0.50)	-	-	-	Dorper[c]	Kariuki *et al.,* 2010
0.07 (0.31)	0.78	-	-	Makooei[b]	Mohammadi *et al*., 2012
0.04 (0.12)	-	-	-	Dormer[b]	Zishiri *et al*., 2010
0.34 (1.21)	-	-	-	Ile de France[b]	Zishiri *et al*., 2010
0.04	-	-	-	Ossimi[b]	Shaat *et al*., 2004
0.09	-	-	-	Rahmani[b]	Shaat *et al*., 2004
0.13	-	-	-	Kurdish[b]	Rashidi & Akheshi, 2007
0.10	-	-	-	Zandi[b]	Mohammadi & Shahrebabak, 2011
0.007 (0.03)	0.79	0.007 (0.03)	0.94	Arman[b]	Farokhad *et al*., 2011
Post weaning weight (kg)					
0.12 (0.57)	0.57	-	-	Madras Red[a]	Balasubramanyam *et al*., 2012
0.11 (0.28)	0.76	0.01 (0.03)	0.72	Moghani[a]	Hossein-Zadeh, 2012
0.16 (0.67)	0.71	-	-	Kermani[b]	Mokhtari & Rashidi, 2010
0.09 (0.30)	-	-	-	Tropical fat tailed[c]	Negussie *et al*., 2002
0.16 (0.44)	-	-		Dorper[c]	Kariuki *et al.,* 2010
0.05 (0.12)	0.88	-	-	Makooei[b]	Mohammadi *et al*., 2012
0.46 (1.69)	-	-	-	Malpura[b]	Arora *et al.,* 2010
0.04	-	-	-	Zandi[b]	Mohammadi & Shahrebabak,

					2011
0.15 (0.26)	0.72	-	-	Dohne Merino[e]	Cloete *et al*., 1998
0.63 (1.20)	0.94	-	-	Merino[d]	Olivier *et al*., 1995

[a]: selected for body weight; [b]: undefined; [c]: unselected; [d]: selected for clean fleece weight with limitations on fibre diameter; [e]: selected for increased body weight, decreased fibre diameter and maintenance of clean fleece weight; *: not significant; R^2: coefficient of determination

The Weaning Weight Maternal selection line recorded a much higher genetic decline for birth weight in the current study compared to the literature in Table 4.2. The Kurdish sheep reported on by Rashidi & Akheshi (2007) recorded a genetic increase of 0.02 kg per annum, which corresponded in magnitude with the Weaning Weight Maternal selection line, except that the current study recorded a decline of 0.02 kg per annum. The maternal genetic progress for birth weight ranged from 0.04% for Moghani sheep (Hossein-Zadeh, 2012) to 0.54% for Arman sheep (Farokhad *et al*., 2011). Mohammadi *et al*. (2012) reported 0.17% per annum for Makooei sheep which corresponded well with the value of 0.18% in the Weaning Weight Maternal selection line of the current study. Mohammadi & Shahrebabak (2011) recorded an increase of 0.005 kg per annum (Table 4.2) in the maternal genetic progress for birth weight, which was similar to the response of 0.007 kg obtained in the Weaning Weight Maternal selection line of the current study (Table 4.1).

From Table 4.2 it was evident that the reported levels of direct genetic progress in weaning weight had a big range for the percentage gain per annum. It ranged from 0.03% for Arman sheep to 1.21% for Ile de France sheep (Farokhad *et al*., 2011; Zishiri *et al*., 2010). The reported value of 0.71% for the direct genetic increase in weaning weight for the Madras sheep of Balasubramanyam *et al*. (2012) corresponded well with the annual genetic gain of 0.79% for weaning weight in the Weaning Weight Direct selection line of the current study. Mohammadi *et al*. (2012) reported a 0.31% per annum direct genetic increase for Makooei sheep, while a selection response of 0.13 kg per annum was found in Zandi sheep (Rashidi & Akheshi, 2007). These values were comparable to genetic responses of 0.41% and 0.12 kg in the Weaning Weight Both selection line of the current study. It should be noted that the genetic response for weaning weight in the Weaning Weight Both selection line was likely compromised because of the emphasis also placed on maternal breeding values in this line. The response in the Weaning Weight Direct selection line is a truer reflection of the gains that could be expected to accrue from selection for direct breeding values for weaning weight.

Reports of maternal genetic responses in weaning weight are much less common in the literature. Hossein-Zadeh (2012) reported a 0.21% maternal genetic increase in weaning weight of Moghani sheep, which was broadly similar to the comparable value of 0.3% recorded for the Weaning Weight Direct line. The 0.03% genetic increase in weaning weight of Arman sheep

(Farokhad *et al*., 2011) were consistent with the response in the Weaning Weight Maternal line of the current study.

The direct genetic changes in yearling weight ranged from 0.12% per annum for Makooei sheep (Mohammadi *et al*., 2012) to 1.69% per annum for Malpura sheep (Arora *et al.,* 2010; Table 4.2). The derived selection response of 0.27% per annum in yearling weight for the Weaning Weight Maternal selection line from the current study corresponded well with the results from Hossein-Zadeh (2012) and Cloete *et al*. (1998) in Table 4.2 (0.28 and 0.26% per annum respectively). It should be noted that the genetic change in the latter study (Cloete *et al*., 1998) was achieved with quite worthwhile genetic change in clean fleece weight (0.81% per annum) while fibre diameter was also improved at -0.05% per annum. With the known unfavourable genetic correlation of fibre diameter with the other traits (Safari *et al*., 2005), this was still an acceptable outcome in terms of overall economic yield. The Dohne Merino breed studied by Cloete *et al*. (1998) were selected for an increase in clean fleece weight and a simultaneous reduction in fibre diameter, whereas the Moghani and Madras Red sheep were only selected for an increase in body weight. Direct genetic progress amounting to 0.57% per annum in Madras Red sheep studied by Balasubramanyam *et al*. (2012) was in agreement with the value of 0.58% per annum in the Weaning Weight Both selection line from the current study.

It should be reiterated that the genetic change in yearling weight in the latter line was probably constrained by the emphasis also placed on maternal breeding values. At 1.01% per annum, the observed genetic gain in yearling weight of the Weaning Weight Direct selection line of the current study was acceptable. However, it was still lower than the comparable value of 1.69% reported by Arora e*t al*. (2010) in Malpura sheep. The Grootfontein Merino stud showed a comparable direct genetic change of 1.2% per annum (Olivier *et al*., 1995) for hogget weight. This value is quite similar to the value of 1.01% per annum recorded in the Weaning Weight Direct selection line for yearling weight. It is notable that selection on visual appraisal only resulted in a genetic change of 0.41% per annum in hogget weight in the study by Olivier *et al*. (1995), while the faster gain of 1.2% per annum resulted from selection on the BLUP of breeding values in a later era. In contrast to the present study, Olivier *et al*. (1995) reported genetic trends stemming from a multi-trait breeding objective, namely to increase body weight, to reduce in fibre diameter and to maintain clean fleece weight.

4.5 Conclusion

This study found that substantial genetic gains of between 0.8 to 1.0% were attainable by selection on direct breeding values for weaning weight in the Weaning Weight Direct line. These

responses were expected to follow on direct selection for a well-defined growth trait. The direct responses in the Weaning Weight Direct line for weaning and yearling weights were consistent with the selection pressure that was applied. Responses to selection for maternal breeding values in the Weaning Weight Maternal and Weaning Weight Both selection lines were disappointing and require further study.

As the Dormer is a terminal sire breed for crossbreeding with Merino-type dams it is important to increase the rate of direct genetic gain for early growth while keeping direct and maternal genetic gains in birth weight to a minimum. The outcome of this study was satisfactory since this objective was largely realized. In light of the emphasis of selection for conformation traits in the South African sheep industry, it would be interesting to quantify what the effect of the selection for growth traits will have on these traits.

4.6 References

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Chapter 5
Differences in growth, wool traits and lamb survival of South African Mutton Merino and Dormer sheep in the same environment

Abstract

This study evaluated differences in live weights, lamb survival and wool traits of South African Mutton Merino (SAMM) and Dormer sheep. The flocks used were the foundation flocks of the respective breeds in South Africa and were maintained at the Elsenburg Research Farm in the Western Cape. Early growth and lamb survival data over a 14-year period (2006 - 2019) and yearling weight and wool data over a 4-year period (2015 - 2018) were used to derive breed differences in ASREML. SAMM lambs were significantly heavier at birth compared to their Dormer contemporaries (4.19 vs. 4.13 kg). Dormers were heavier than SAMMs at weaning (27.3 vs. 25.0 kg) and also when weighed as yearlings (49.7 vs. 47.8 kg). Dormer lambs had a higher survival rate than SAMM lambs at 0.89 and 0.81, respectively. Clean fleece weight was the only wool trait not affected by breed (P = 0.12). Wool from Dormer yearlings had a higher clean yield, clean fleece weight and staple length than wool from SAMM yearlings (P < 0.01). In contrast, SAMM yearlings had lower coefficient of variation of fibre diameter and finer wool than their Dormer contemporaries (respectively 22.4 vs. 28.6 µm; P < 0.001). Breed interacted with birth weight for lamb survival, the best survival rate of Dormer lambs being at a somewhat lower birth weight than that of SAMMs. Breed also interacted with birth year and dam age, suggesting that the effect of breed was not consistent across all fixed effect classes. Although Dormers competed well with SAMMs for the quantitative wool traits, their stronger carpet wool would fetch markedly lower prices than the apparel wool produced by SAMMs. Other traits mostly followed trends reported in the literature.

5.1 Introduction

An increase in the efficiency of sheep production systems can be achieved by enhancing the net reproduction rate, shortening the production cycle and optimizing the wool production of animals (Olivier, 1999). The Dormer is a prominent local terminal sire breed in South Africa, while the South African Mutton Merino (SAMM) is a dominant dual-purpose breed (Cloete *et al*., 2014). The traits routinely recorded for both breeds in the National Small Stock Improvement Scheme only include birth weight, weaning weight, post-weaning weight and reproduction (Schoeman *et al*., 2010). No emphasis is thus directed at wool traits in either breed.

Breeders often change from one breed to the other mainly due to perceived short-term financial reasons as a result of fluctuations in wool and meat prices (Zishiri *et al*., 2010).

Profitability of sheep production for meat depends to a great extent on weaning weight (Tosh & Kemp, 1994). Birth weight and early growth rate, especially until weaning, is determined by the animals' own genetic potential, but also by its maternal environment (Mandal *et al*., 2006). Lamb mortality is an important source of reproductive failure in all sheep production systems (Dalton *et al*., 1980). Perinatal lamb mortality is recognised as an important source of reproductive wastage, resulting in economic losses (Alexander, 1984) and ethical concerns (Brien *et al*., 2014). Cloete (1992, 1993, 1994), Cloete *et al*. (1993, 1998b, 2002), Brand *et al*. (1985) as well as Kritzinger *et al*. (1984) have previously investigated the reproductive rate and lamb mortality of Dormer and SAMM sheep.

The major sources of income for commercial sheep farmers are from the sale of wool and lambs for slaughter. The value of wool is influenced by quantity and quality, and the value of slaughter lambs is related to liveweight and fat depth (Brash *et al*., 1994b). The aim of breeders of the above-mentioned breeds is to increase productivity and profitability of their breeds. Lamb meat prices continue to be favourable, even while income derived from wool has increased considerably over the past few years (Van der Merwe, 2020). There is considerable interest in breeding animals for wool, meat, reproductive capacity and disease traits simultaneously (Brown & Fozi, 2005). Van der Merwe *et al*. (2020) and Cloete *et al*. (2004b; 2012) have previously compared the slaughter weight, carcass composition and meat quality of Dormers and SAMMs.

Fibre diameter is the primary aspect determining wool quality and contributes greatly to the spinning performance, resulting in the finest wool being the most valuable (Erasmus & Delport, 1987; Van Graan *et al*., 2014). Fibre diameter is determined by the genotype of the animal, which determines the size and capacity of their follicles. However, external factors such as nutrition also play an important role. In the advent of an increase in wool production caused by an improved level of nutrition, there is likely to be an unwanted increase in the mean fibre diameter (Khan *et al*., 2012). However, live weight and particularly clean fleece weight are much more prone to fluctuations of environmental origin than fibre diameter (Hunter *et al*., 1990; Cloete *et al*., 1992). There are differences between breeds in their capacity to grow wool as well as in individual wool traits. Fine wool breeds have a greater follicle density than coarse wool breeds indicating that they can produce a similar weight of wool but produce more yarn than coarse wool breeds with a reduced follicle density (Khan *et al*., 2012). Within breeds there is also variation in the rate of wool growth. Fine, medium and coarse wool breeds show increasing clean fleece weights that is associated with an increased fibre diameter, staple length and live weight. Fleece weight per area is influenced by the number of follicles, staple length and fibre diameter (Olivier & Olivier, 2005). Many characteristics underlying wool traits and follicle structure are highly heritable and significant changes can be made by selection for the desired

characteristics, while also considering that the key traits of fleece weight and fibre diameter are unfavourably correlated (Khan *et al*., 2012).

Differences in profitability between sheep breeds remains one of the most controversial issues among sheep farmers (Snyman *et al*., 1995). Apart from information supplied in Chapters 2 and 3, the background of the respective resource flocks was thoroughly described by Van der Merwe (1967), Van Wyk *et al*. (2003) and Fair (2002) for the Dormer breed and Vosloo (1967), Zemuy (2002) and Cloete *et al*. (2004a) for the SAMM breed. Selection in both breeds was mostly based on early growth and conformation, although realised genetic gains in weaning weight were disappointing, particularly in SAMMs (see Chapters 2 and 3). Against this background, the aim of this study was to compare these breeds for certain live weights, lamb survival and wool traits and to quantify the affect that fixed effects have on these traits and breeds.

5.2 Materials and Methods

5.2.1 Animal resources, the environment and management

Data from the Dormer and SAMM resource flocks of the Elsenburg Research Farm were used to investigate differences in the growth and wool traits and lamb survival. The Elsenburg Research Farm is located near Stellenbosch in the Western Cape, South Africa. The experimental animals were maintained in the same flock for the duration of this study, rendering them comparable. The history, environment and management of both flocks were thoroughly discussed in Chapters 1, 2 and 3. Data for growth traits were recorded during a 14-year period from 2006 to 2019 and data for yearling weight and wool traits from 2015 to 2018 were used to ensure that the animal were in the same comparable contemporary groups.

5.2.2 Data recorded and selection practices implemented

Practices for the recording of traits in both flocks from birth to yearling age were thoroughly discussed in Chapters 2 and 3. On average (±SD), weaning weight was measured at 104 ± 13 days of age and yearling weight at 322 ± 9 days of age.

5.2.3 Statistical analysis

Traits that were analysed included birth weight, weaning weight and lamb survival from 2006 to 2019; and yearling weight, clean yield, clean fleece weight, staple length, coefficient of variation (CV) of fibre diameter and fibre diameter from 2015 to 2018. Data were analysed using ASREML (Gilmour *et al*., 2016). The software allows for the analysis of mixed models using a range of fixed and random effects in animal models. Fixed effects included in single-trait models

for all traits were breed (SAMM or Dormer), birth year (2006 – 2019 for birth weight, weaning weight and lamb survival; 2015 – 2018 for yearling weight and wool traits), age of dam (2 - 6+ years), sex (male or female), birth type (single, twin and triplet for birth weight, lamb survival and weaning weight, where adequate numbers were available; single and pooled multiples for yearling traits), two-factor interactions of breed with birth year, dam age and birth type as well as between sex and birth year. Age at measurement was included as a linear covariate where applicable. The random effects of sire and dam permanent environment were included in analyses for the variation it controlled. A *P*-value of < 0.05 was regarded as significant in all analyses.

Ethical clearance for this study was obtained from the Departmental Ethics Committee for Research on Animals (DECRA) of Western Cape Department of Agriculture (reference number – R12/55 and R12/59).

5.3 Results and Discussion

5.3.1 Environmental effects denoted by predicted fixed effect means

Early-life traits were represented by 3627 records for birth weight, 3205 records for weaning weight and 3647 records for lamb survival. The number of yearling records ranged from 760 for clean fleece weight to 794 for fibre diameter. All growth and yearling traits were influenced by birth year (*P* <0.001), a result consistent with those of Cloete *et al.* (2007) as well as in Chapters 2 and 3. However, birth year effects were not tabulated as birth years are transient and not repeatable. Birth year effects also depend on a combination of unique climatic and managerial effects, for example the quantity of and variation in rainfall that could vary and affect the grazing. This is important, seeing that the animals were predominantly pasture-fed throughout the study. The birth year and sex interaction were evident in traits such as yearling weight, clean yield, coefficient of variation of fibre diameter and fibre diameter (*P* <0.01). This interaction is explained by the fact that for both breeds lambs were maintained in the same flock but separated on sex after weaning (Chapters 2 and 3). It is difficult to ensure that grazing conditions are similar for separately grazed ewe and ram flocks (Brash *et al*., 1994a; 1994b; Cloete *et al*., 1998a), a factor that contributes to this interaction. These interactions corresponded with comparable results in Chapters 2 and 3.

Sex affected all the traits in the study except for clean fleece weight, while it only approached significance for lamb survival (*P* =0.05). However, in Chapter 2 sex was found to have a significant effect on lamb survival and clean fleece weight in SAMM, when using substantially more records than what were available here. Sex did influence coefficient of

variation of fibre diameter and fibre diameter. The analysis in Chapter 3 similarly found that all Dormer traits depended on sex (P <0.05).

In this analysis birth type affected birth weight, weaning weight, lamb survival, yearling weight, clean fleece weight and coefficient of variation of fibre diameter (P <0.001), but did not influence clean yield, staple length and fibre diameter. Significant birth type effects for all traits except for clean yield were also reported in Chapter 2. Analysis in Chapter 3 found that birth type affected the growth traits, lamb survival, yearling weight, clean fleece weight, staple length and coefficient of variation of fibre diameter, but not clean yield and fibre diameter. This was thoroughly discussed in Chapters 2 and 3 for SAMMs and Dormers, respectively. Dam age only influenced the growth traits such as birth weight and weaning weight (P >0.001) and thorough explanations for this were also provided in Chapters 2 and 3.

5.3.2 The effect of breed

Weaning weight of the lambs of both breeds were measured at 104 ± 13 days of age and increased on average with 0.15 kg per day of age. Yearlings were weighed at 322 ± 9 days of age and gained on average 0.21 kg per day of age. These linear regressions are a good representative of both breeds together. The linear regressions of weight on weaning and yearling age in Chapters 2 and 3 amounted to respectively 0.26 ± 0.06 kg/day and 0.16 ± 0.01 kg/day for SAMMs and 0.14 ± 0.01 kg/day and 0.22 ± 0.07 kg/day for Dormers. Brash *et al*. (1994a; 1994b) reported the linear regressions for weight on age for dual-purpose Corriedale and Coopworth lambs respectively as 0.096 ± 0.005 and 0.205 ± 0.006 kg/day for weaning weight and 0.084 ± 0.01 and 0.105 ± 0.10 kg/day for yearling weight.

Table 5.1 predicted means for the effect of breed on lamb survival, growth and yearling traits. The SAMM lambs were 7.7% heavier than Dormer lambs at birth. In contrast, Dormers were heavier by 9.2% at weaning and by 4.0% as yearlings compared to SAMMs (Table 5.1). Results from Brand *et al*. (1985) agreed with this finding for birth (4.6 vs 4.2 kg). Muller *et al*. (2019) reported similar results for weight traits using fewer records of the same SAMM and Dormer resource flocks where SAMMs were 7.84% (4.95 vs 4.59 kg) heavier than Dormers at birth, while Dormers were 6.8% (29.7 vs 27.8 kg) heavier at weaning age and 13.9% (52.5 vs 46.1 kg) heavier at yearling age (P <0.01). Cloete (1993) reported that SAMM lambs were 5.0% heavier than Dormers, at 4.2 vs 4.0 kg respectively (P <0.01). According to Cloete *et al*. (1998b) the yearling live weights of the breeds did not differ and amounted to 67.1 kg for SAMMs and 68.3 kg for Dormers. Van Wyk *et al*. (2003), using data from the same Dormer flock, and Zishiri *et al*. (2014), using data of the national flock, reported similar birth weights of respectively 3.9 and 3.8 kg, but heavier weaning weights (ranging from 74 – 126 days of age) of respectively 29.0 and 33.0 kg. Cloete *et al.* (2004a) recorded yearling live weight of lambs in the same

SAMM flock as 50.7 kg, which did not correspond well with the yearling weight in the current study. This could be ascribed to the auctioning of lambs prior to 2000 that caused heavier live weights. The study of Cloete *et al*. (2001) reported higher weaning (110 ± 22 days of age) and yearling weights (10 – 12 months of age) for SAMM lambs of the Mariendahl flock than in the present study of respectively 32.1 and 57.9 kg. Neser *et al*. (2000) reported the average weaning weight (100 days of age) of SAMM lambs of the national flock as 30.6 kg, which were higher than the mean value of the current study. It is important to note that most of the means that are offered for comparison are from flocks managed as "studs", which would entail higher levels of concentrate feeding than applied to the pasture-fed Elsenburg animals.

Table 5.1 Predicted means (± SE) depicting the effect of breed (South African Mutton Merino - SAMM or Dormer) on lamb survival, growth and yearling traits.

Trait	Breed		Significance
	SAMM	Dormer	
Growth traits and lamb survival			
Birth weight (kg)	4.36 ± 0.058	4.05 ± 0.057	***
Weaning weight (kg) at 104 ± 13 days	25.0 ± 0.35	27.3 ± 0.34	***
Lamb survival	0.81 ± 0.015	0.89 ± 0.014	***
Yearling traits			
Yearling weight (kg) at 322 ± 9 days	47.8 ± 0.84	49.7 ± 0.79	*
Clean yield (%)	65.7 ± 1.07	72.7 ± 0.84	***
Clean fleece weight (kg)	1.89 ± 0.084	2.04 ± 0.071	0.12
Staple length (mm)	88.9 ± 2.87	99.8 ± 2.28	**
Coefficient of variation of fibre diameter (%)	16.0 ±0.35	17.7 ± 0.29	***
Fibre diameter (µm)	22.4 ± 0.43	28.6 ± 0.34	***

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; actual significance for $P > 0.05$

Dormers had a 9.88% higher probability of survival from birth to weaning than their SAMM contemporaries (P <0.001; Table 5.1). Cloete (1994) reported that lambs reared per lamb born amounted to respectively 0.75 and 0.44 for "good" and "poor" SAMM ewes and to 0.79 and 0.45 for "good' and "poor" Dormer ewes. The latter study allocated ewes to groups according to their lifetime rearing performance and compared the groups for the size and shape of their pelvises. Cloete (1992) reported that the mortality levels was higher at birth and from 3 days to weaning for SAMM lambs compared to Dormer lambs (P <0.05), but that there was no breed difference in mortality for number of lambs weaned per ewe (P >0.05). Van Wyk *et al*. (2003) reported a corresponding lamb survival rate of 0.82 for Dormer lambs of the same flock for the period from 1943 to 2002. Cloete *et al*. (1993) also reported fewer perinatal deaths in Dormer lambs than in SAMM lambs.

It is important to note that this is the first study of a fairly large scale to the author's knowledge that compares yearling wool traits of Dormers and SAMMs. The only previous study by Van der Merwe (2020) that could be sourced used small numbers (SAMM = 20 animals;

Dormer = 19 animals) of younger animals being fed concentrate diets in a feedlot. Thus, apart from citing the results from Van der Merwe (2020), this study also draws on results published previously for this and other Dormer and SAMM populations. The average clean yield of wool from Dormer yearlings was 10.7% higher relative to wool from SAMM yearlings (P <0.001; Table 5.1). Van der Merwe (2020) reported no significant difference between the wool of breeds for clean yield. The clean yield of wool from SAMM yearlings from the same flock recorded from 1983 to 2002 and reported by Cloete *et al*. (2004a) corresponded well with the mean value of 66.1% in the current study. Clean fleece weight was the only trait that did not differ between the two breeds (P =0.12). South African Mutton Merino yearlings reported by Cloete *et al*. (2004a) recorded a higher clean fleece weight of 2.15 kg on the same SAMM flock. Cloete *et al*. (2001) reported a similar clean fleece weight of 1.6 kg for SAMMs of the Mariendahl flock for the period from 1980 to 1994. Dormer yearlings produced 12.3% longer staples than SAMM yearlings (P <0.01; Table 5.1). Staple length did not differ between the two breeds in the smaller study of Van der Merwe (2020). A comparison of fine and coarse wool breeds suggested an increased clean fleece weight associated with an increased fibre diameter, staple length and live weight in coarse wool breeds (Khan *et al*., 2012).

South African Mutton Merinos had a 9.6% lower CV of fibre diameter than their Dormer contemporaries (P <0.001; Table 5.1). The findings of Van der Merwe (2020) compared well with the present study with SAMMs having a 19.2% lower CV of fibre diameter compared to Dormers. SAMM yearlings produced 21.7% finer wool than Dormers (P <0.001; Table 5.1). Van der Merwe (2020) reported corresponding means for fibre diameter of wool from SAMM and Dormer yearlings of 23.3 and 31.3 µm, respectively. It should be noted that the latter study involved concentrate feeding in a feedlot and traits were measured at approximately 12 months of age. SAMM yearlings in the studies of Cloete *et al*. (2001; 2004a) were reported to have corresponding means for fibre diameter of 23.0 and 23.7 µm, respectively.

5.3.3 Interactions of breed with other fixed effects and regressions

Birth weight influenced lamb survival (P <0.001) in a curvi-linear fashion. Breed also interacted with birth weight for lamb survival (P <0.001). The survival of Dormer lambs peaked at a birth weight of approximately 5 kg with a mean proportion of 0.90 lambs surviving. The survival of SAMMs peaked at a birth weight of 6 kg and at a 0.88 survival rate. Survival of both breeds decreased at higher weights (Figure 5.1). Lambs with intermediate birth weights evidently had the best survival rate, while survival is compromised in lambs with high and low birth weights (Hight & Jury, 1970; Dalton *et al*., 1980; Brand *et al*., 1985; Cloete, 1993).

Figure 5.7 Predicted means illustrating the interaction of breed with the quadratic regression of lamb survival on birth weight for SAMM and Dormer lambs. The vertical lines about means denote standard errors.

An interaction between breed and birth year was observed for birth weight, weaning weight and lamb survival (P <0.01). During the 14-year study period, SAMM lambs were initially heavier (P <0.05) than Dormer lambs at birth for the period from 2006 to 2013, differences ranging from 7.4 to 21.1% expressed relative to means for Dormers (Figure 5.2). This result was expected based on previous research (Brand *et al*., 1985; Cloete, 1992). Post 2013, SAMM lambs were only heavier than Dormers during 2017 and 2019, respective differences amounted to respectively 5.2 and 6.4% (P <0.05). It is notable that the reduced breed differences since 2014 coincided with the selection regime reported in Chapter 4, when the Dormer flock was selected on direct and/or maternal breeding values for weaning weight. It was evident that maternal breeding values for birth weight in the weaning weight direct line, in particular, was between 0.1 and 0.2 kg higher since 2014. At this stage it is uncertain if this selection was involved in the observed interaction, suggesting the need for further research.

Figure 5.3 presents the breed by birth year interaction for weaning weight. Dormers were mostly heavier than SAMMs at weaning, breed differences ranging from only 5.5% in 2016 to 21.9% in 2009 (P <0.05). During 2017 and 2018 there were no significant differences in weaning weight between the two breeds, although absolute values still favoured Dormers. Based on the literature (Brand *et al*., 1985; Muller *et al*., 2019), Dormers were expected to be heavier than SAMMs, as was found in the majority of years reported on.

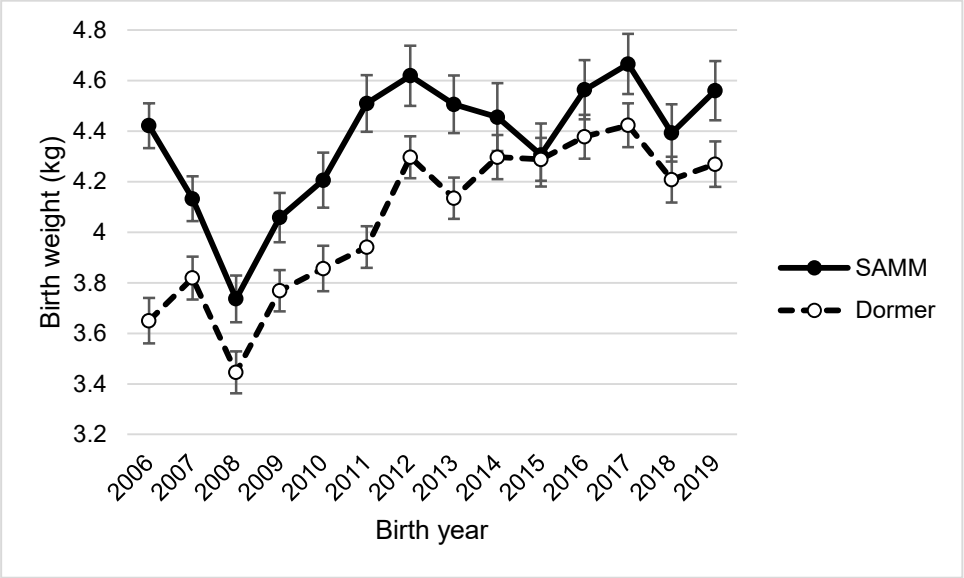

Figure 5.2 Predicted means illustrating the interaction of breed and birth year for birth weight of SAMM and Dormer lambs. The vertical lines about means denote standard errors.

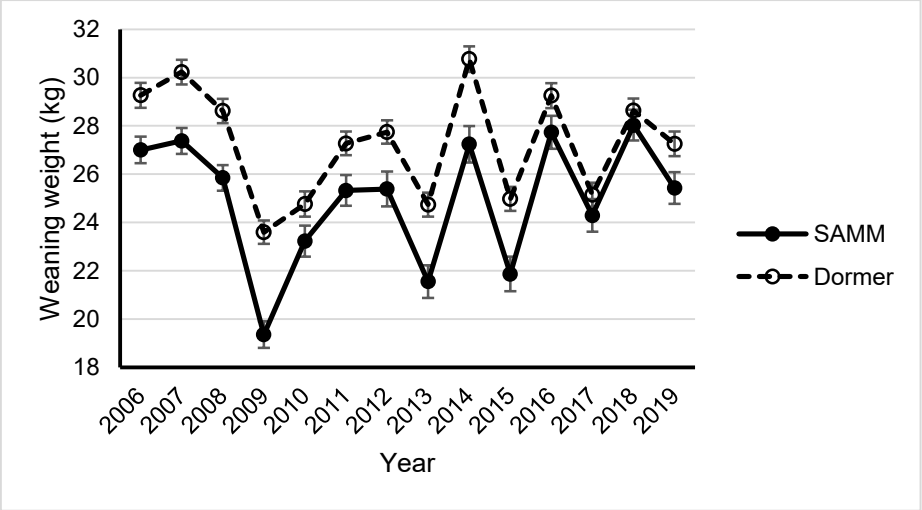

Figure 5.3 Predicted means illustrating the interaction of breed with birth year for weaning weight of SAMM and Dormer lambs. The vertical lines about means denote standard errors.

Figure 5.4 illustrates the breed by birth year interaction for lamb survival. Survival of Dormer lambs was more stable at 0.84 to 0.97 across years. In contrast, survival of SAMM lambs were more variable, ranging between 0.66 and 0.92 with quantitatively large breed differences in 2006 and 2012, where Dormer lambs had respectively a 37.3 and 22.6% better survival rate than SAMM lambs. Significant breed differences in favour of Dormers were found during the period from 2006 to 2009, as well as for 2012, 2017 and 2019. A better overall survival of Dormers than SAMMs (0.89 vs 0.81) corresponds well with reports by Brand et al. (1985), Cloete (1992) and Cloete *et al*. (1993).

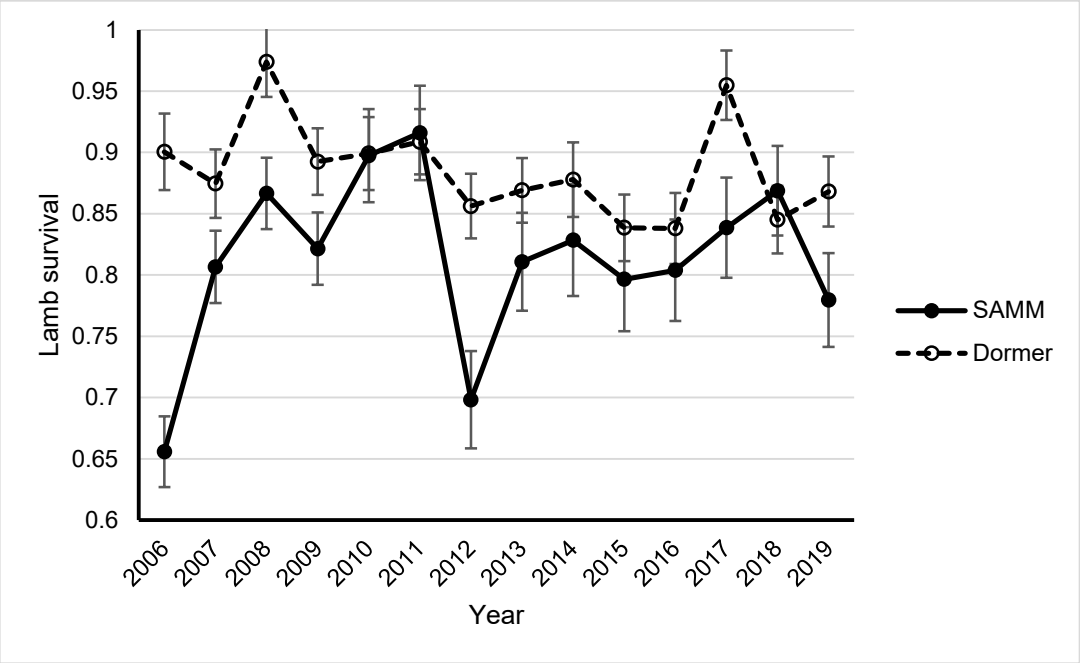

Figure 5.4 Predicted means illustrating the interaction of breed with birth year for lamb survival of SAMM and Dormer lambs. The vertical lines about means denote standard errors.

Breed interacted with birth type and age of dam for birth weight (*P* <0.001). The only significant breed difference was observed for singles; SAMM singles being 9.6% heavier than Dormer singles at respectively 5.41 ± 0.06 kg vs. 4.93 ± 0.05 kg (P <0.05). The breed difference for twins were somewhat reduced at 6.6%, with birth weight means for SAMMs and Dormers amounting to respectively 4.29 ± 0.05 kg vs. 4.02 ± 0.05 kg (P <0.05). In contrast, no conclusive significant breed differences in birth weight were found in triplets, where means amounted to respectively 3.38 ± 0.09 kg and 3.21 ± 0.11 kg (P >0.05). No evident reason could be found for the lack of a breed difference for triplets, but it needs to be acknowledged that substantially fewer triplets were available. Means were thus estimated with a larger error than for the other birth type classes.

According to Figure 5.5, SAMM lambs were generally heavier at birth. Breed differences ranged from 5.12% for 2-year-old dams to 10.3% for 5-year-old dams in favour of SAMM lambs (*P* <0.01). The birth weight of SAMM lambs were quite stable for 3- to 6+-year-old dams, ranging from 4.35 ± 0.065 to 4.55 ± 0.067 kg. In contrast, the birth weight of Dormer lambs increased further in the progeny of 6+-year-old dams relative to the progeny of 5-year-old dams.

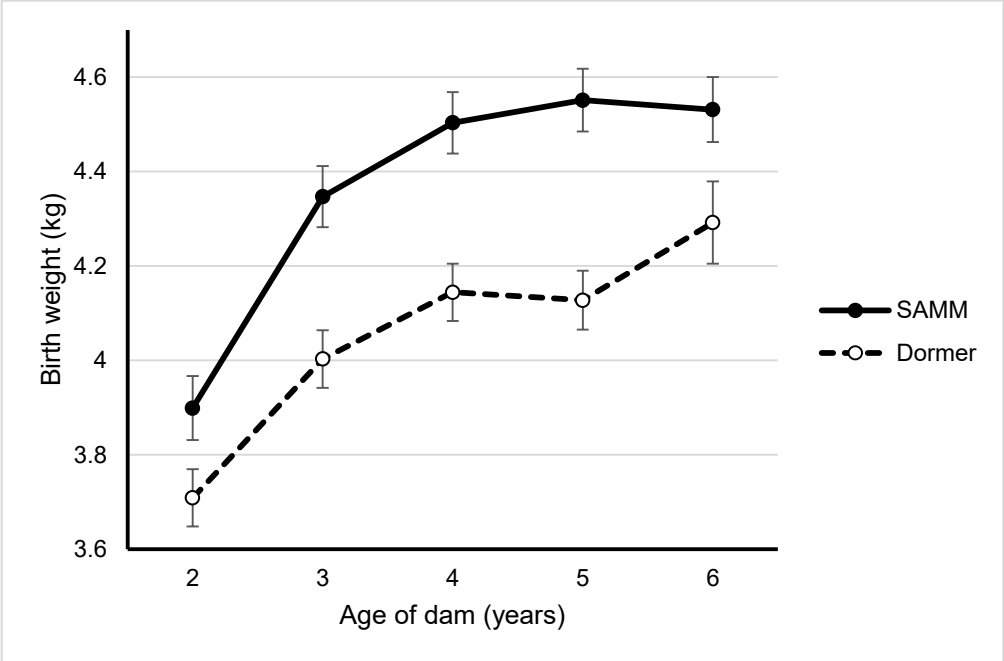

Figure 5.5 Predicted means illustrating the interaction of breed with dam age for birth weight of South African Mutton Merino - SAMM and Dormer lambs. The vertical lines about means denote standard errors.

5.4 Conclusion

The breed differences between SAMMs and Dormers showed that the breeds differed for birth weight, weaning weight and yearling weight as well as certain wool traits and lamb survival. The SAMM lambs were heavier at birth than Dormers, while Dormers were slightly heavier than SAMMs at weaning and yearling weight. Dormer lambs had better survival rates from birth to weaning than SAMM lambs. The breed differences could be ascribed to the different roles that these breeds play in South Africa, Dormers being a terminal sire breed where direct early growth is emphasized during selection. The role of the SAMM as a dual-purpose breed warrants a different selection objective. Furthermore, the SAMM would also receive better prices for their finer wool when marketed as apparel wool.

There were several instances where breed interacted with other fixed effects, suggesting that breed effects were not consistent over the levels of other fixed effects. In most cases, the significance of breed differences did not follow a discernable trend. However, in the interaction of breed with birth year for birth weight, there was a suggestion that Dormers became heavier at birth as time progressed and that this result could potentially be ascribed to the selection regime in this flock that was described in Chapter 4. This result warrants further research.

The only component of reproduction considered in this study was lamb survival. It is therefore suggested that the reproduction of Dormer and SAMM sheep should be compared in

the same environment. The different roles these breeds play in the South African sheep industry make a direct economic comparison on product quality and yield difficult. However, by including reproduction in such a comparison might yield interesting results.

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Chapter 6
Differences in carcass and meat quality traits of South African Mutton Merino and Dormer sheep in the same environment

Abstract

The Dormer and the South African Mutton Merino (SAMM) are respectively the most important terminal sire and one of the most important dual-purpose sheep breeds in South Africa. This study investigated the effects of breed and other fixed effects on carcass and meat quality traits on the Elsenburg SAMM and Dormer resource populations from 2016 to 2019. The number of records ranged from 238 for shear-force to 461 for pH measured 48 hours post slaughter. Birth year influenced all traits and interacted with sex for most traits, while all traits were independent of dam age. The two breeds did not differ for slaughter weight, carcass weight or dressing percentage. Dormers had a thicker subcutaneous fat cover at the rump than SAMM contemporaries. The cooking loss of SAMM meat was higher compared to Dormer meat. Dormer meat was slightly darker and redder than SAMM meat, but this difference in colour would not be visually perceivable by consumers. There was no difference in meat tenderness between the two breeds. Rams were heavier with a lower dressing percentage than ewes. Ewes had a greater subcutaneous fat depth than rams. Ewe meat samples were characterised by a higher cooking loss and a lower drip loss compared to rams. Ram meat was slightly lighter with a higher shear-force than that of ewes. Singles were heavier with a higher dressing percentage than multiples. The differences between breeds for carcass and meat quality traits were very small and both breeds would excel at meat production.

6.1 Introduction

There is a diversity of sheep breeds and crosses in South Africa, including specialist breeds for meat and wool production (Hoffman *et al.*, 2003). Sheep bred for wool production are known to underperform for growth and carcass output relative to meat and dual-purpose breeds (Cloete *et al*., 2012). The economy of wool sheep farming is influenced by fluctuating wool prices and ever-increasing input costs, therefore the focus shifted from wool to meat production (Van der Merwe, 2020). Wool farmers are forced to include meat sires in their flocks as part of a terminal crossbreeding enterprise to increase cash flow and turnover (Hoffman *et al.*, 2003).

The Dormer is a prominent local terminal sire breed, while the South African Mutton Merino (SAMM) is one of the dominant dual-purpose breeds (Cloete *et al.*, 2014). The Dormer was developed in the 1940s, at the then Elsenburg Research Farm when Dorset Horn rams

were crossed with German Merino ewes to establish a new composite breed (Van Wyk *et al.*, 2003). The Dormer was developed as a terminal sire breed for crossbreeding with wool breeds (Van der Merwe *et al.*, 2019).

The SAMM originated from the German Merino, which was imported to South Africa in 1932 (Cloete et al., 2004a). The foundation flock was kept at Elsenburg, from where it spread throughout South Africa and to other countries such as Australia (Cloete *et al.*, 2001; Brown & Fozi, 2005). The breed was used to develop several composite breeds, including the Dohne Merino, Dormer and Afrino.

The traits recorded in both breeds in the National Small Stock Improvement Scheme include birth weight, weaning weight, post-weaning weight and reproduction (Schoeman *et al.*, 2010). No emphasis is thus directed at slaughter traits or meat quality in either breed. Both breeds are regarded as medium maturing breeds, having a high growth rate and grow out to a high mature weight compared to the other South African ovine genetic resources (Van der Merwe *et al.*, 2019). This means that they may have less subcutaneous fat at the same age than contemporaries from early maturing breeds like the Dorper (Cloete *et al.*, 2012). The Dormer and SAMM produce suitable slaughter lambs with desirable meat traits (Neser *et al.*, 2000), while Cloete *et al.* (2012) suggested that Dormer lambs were early maturing when compared to SAMM lambs. Selection in both breeds was mostly based on early growth and conformation. No direct selection pressure was applied for any meat trait.

Previous studies comparing these breeds for meat traits were based on small sample sizes and animals slaughtered at an elevated age of 18 to 20 months (Cloete *et al.*, 2004a; 2012). Van der Merwe *et al.* (2020) studied the effect of breed on the slaughter characteristics of feedlot-finished lambs of seven South African breeds, including SAMMs and Dormers. However, the sample size for the latter study was small and the lambs were slaughtered when the ideal backfat thickness was reached. Furthermore, the lambs were fed concentrate diets.

There is a need to update the earlier results on slaughter traits of pasture-fed lambs with information on animals slaughtered at a more reasonable age. Studies on lamb and mutton indicate that there is variation between breeds for slaughter traits (Sink & Caporaso, 1977). Hoffman *et al.* (2003) also found that breed affected meat quality. Limited research has thus far been done to verify the effect of breed on the eating quality of lamb (Fisher *et al.*, 1999; Safari *et al.*, 2001; Van der Merwe *et al.*, 2020).

Both Dormer and SAMM plays an important role in the South African prime lamb industry. Against this background, this study was designed to evaluate these breeds in terms of slaughter

weight, as well as carcass and meat quality traits at an age aligned with industry practice for extensively reared lambs.

6.2 Materials and Methods

6.2.1 Animal resources, the environment and management

Data were collected from the Dormer and SAMM resource flocks at Elsenburg Research Farm, near Stellenbosch in the Western Cape Province, South Africa. Experimental animals of both breeds were maintained in the same flock for this experiment. More information on the history, environment and management of both flocks can be sourced from the literature (Van Wyk *et al.*, 2003; Cloete *et al.*, 2004b). Data collection for carcass and meat quality traits took place during a four-year period from 2016 to 2019.

6.2.2 Data recorded and selection practices implemented

A total of 461 Dormer and SAMM yearlings born from 2015 to 2018 were slaughtered at an average age of 324 ± 52 days to assess meat traits. The ante mortem treatment was similar for all the sheep within year-sex contemporary groups. Lambs were weighed directly from the pasture 24 hours prior to slaughter to record slaughter weight and were slaughtered at a commercial South African abattoir using techniques previously described by Cloete *et al.* (2004a). The sheep were held in lairage overnight for approximately 18 hours before slaughter, with free access to water. Sheep were slaughtered at random after electrical stunning at 200 V for 4 seconds (JARVIS Electric Stunner), applied to the head of the sheep with stunning tongs. The sheep were immediately exsanguinated, and the carcasses were hung to assist bleeding out before dressing. The pH of the left *Longissimus lumborum* muscle was measured at the 13th rib, 25 mm from the midline, 45 min post-mortem using a handheld pH meter. Carcass temperature was recorded together with pH. To avoid rapid chilling, the dressed carcasses were gradually chilled in a cooling passage for 1 to 2 hours before being chilled in a chiller at 4 °C for 48 hours (McGeehin *et al.*, 2001). After 48 hours, the pH and temperature of the chilled carcasses were recorded again. The cold carcasses were weighed and cold carcass weight was expressed as a percentage of slaughter weight to determine dressing percentage.

At this stage, the subcutaneous back fat depth was measured 25 mm off the midline at the positions of the 13th rib and at the rump between the third and fourth lumbar vertebrae using an electronic calliper as described by Cloete *et al.* (2004a). Loin samples of 8 cm were excised from the *Longgissimus lumborum* on the left side between the 13th rib and 3rd and 4th lumbar vertebrae. These samples were taken in cooler bags to the Stellenbosch University Meat Laboratory immediately after slaughter (a 40 minute drive). After arrival at the laboratory, two

1.5 cm thick slices were cut from these samples at a constant temperature of 14 °C. One slice was used to measure cooking loss and shear-force (Honikel, 1998). Samples were weighed and placed in thin-walled polyethylene bags and cooked in a water-bath at 80 °C for one hour. Cooked samples were removed from the water-bath and cooled in cold water at 4 °C for one hour. Samples were removed from the bags, blotted dry and weighed again. Cooking loss was calculated as the difference in sample weight before and after cooking and expressed as a percentage of initial weight. Warner-Bratzler shear-force was determined on the samples used to determine cooking loss. Three sub-samples with a diameter of 1 cm were cut perpendicular to the grain and assessed in an Instron universal testing machine equipped with a Warner-Bratzler shear head with a 1 mm thick triangular blade with a semi-circular cutting edge (Honikel, 1998). Maximum shear-force values were recorded for each sample and the means was calculated and expressed in Newton (N). Shear-force and tenderness is inversely correlated (Pannier *et al.*, 2014).

The other slice was used for surface colour and drip loss (Honikel, 1998). Surface colour was recorded by a digital calibrated handheld Colour-guide 45/0 colorimeter after being allowed to bloom for 45 min (BYK-Gardner, USA) to determine the following Commission Internationale de L'éclairage (CIE) (1976) colour space parameters: L* (lightness); a* (red-green range) and b* (blue-yellow range). The colorimeter was calibrated using standards provided. Drip loss was then determined by attaching a weighed (20 to 50 g) meat sample to a string and suspending it in an inflated and sealed polyethylene bag, ensuring that the sample did not touch the sides of the bag. These bags were hung in a refrigerator at 4 °C for 24 hours. The samples were then removed from the bags, blotted dry and weighed again to derive drip loss, expressed as a percentage of the original sample weight (Honikel, 1998).

6.2.3 Statistical analysis

Data were analysed using ASREML (Gilmour *et al.*, 2016). The software can be used to analyse mixed models by fitting a range of fixed and random effects in animal breeding. Fixed effects included in single-trait models for all traits were breed (SAMM or Dormer), birth year (2016 to 2019), age of dam (2 to 6+ years), sex (male or female) and birth type (single or pooled multiples), two-factor interactions between birth year and sex as well as between birth year and breed. Slaughter age was fitted as a linear covariate. The random effects of sire and dam permanent environment were included for the variation it controlled, although the sample size was regarded as too small for estimating reliable genetic parameters. A P-value of < 0.05 was regarded as significant in all analyses.

Ethical clearance for the maintenance of the resource flocks was obtained from the Departmental Ethics Committee for Research on Animals (DECRA) of Western Cape

Department of Agriculture (reference number – R12/55 and R12/55). Slaughter data were collected under ethical clearance number EC 160922 – 073 at Pretoria University.

6.3 Results and Discussion

6.3.1 Descriptive statistics

Table 6.1 presents the descriptive statistics of the traits that were investigated for both the SAMM and Dormer breeds. The number of records ranged from 350 for dressing percentage to 442 for slaughter weight (Table 6.1). Coefficient of variations amounted to 15.9% for slaughter weight, 18.8% for carcass weight and 9.9% for dressing percentage. Data of between 238 and 461 records for respectively shear-force and pH after 48 hours were available for meat quality traits. The CVs for these traits ranged from below 10% for pH and lightness to more than 70% for fat depth.

Van der Merwe *et al*. (2020) studied the effect of breed on the slaughter characteristics of feedlot-finished lambs slaughtered at a predetermined fatness level according to ultrasound scanning. The sample size of the latter study (n = 148 across the seven breeds studied) was much smaller compared to the current study. Lambs in the latter study were also slaughtered at a much younger age (110 days for Dormers and 114 days for SAMMs) compared to the slaughter age of 324 days in the current study. The lambs studied by Van der Merwe *et al*. (2020) were finished under *ad libitum* conditions in a feedlot whereas the lambs in the present study were pasture-fed. Cloete *et al*. (2012) reported breed differences between SAMMs and Dormers for carcass and meat quality traits when slaughtered at 20 months of age in a study consisting of a much smaller sample size (n = 79). A previous study by Cloete *et al*. (2004a) on these breeds also had a much smaller sample size and sheep were slaughtered at 18 months of age (n = 96).

Table 6.1 Descriptive statistics for carcass and meat quality traits at 324 ± 52 days of age in the Elsenburg SAMM and Dormer flocks collected from 2006 to 2019.

Trait	N	Mean	SD	CV (%)	Range
Carcass traits					
Slaughter weight (kg)	442	50.0	7.92	15.9	22.5 - 71.00
Carcass weight (kg)	371	21.2	3.98	18.8	8.2 - 32.2
Dressing percentage (%)	350	42.5	4.18	9.84	28.3 - 55.6
Meat quality traits					
pH 45 min	351	6.73	0.44	6.54	5.45 - 7.30
pH 48 hr	461	5.73	0.28	4.89	5.14 - 6.90
Temp 45 min (°C)	459	29.8	4.64	15.6	17.5 - 38.0
Temp 48 hr (°C)	431	4.94	1.18	23.9	3.1 - 8.4
Fat 13th rib (mm)	407	1.76	1.32	75.0	0.3 - 6.8
Fat rump (mm)	408	3.65	2.62	71.8	0.4 - 13.4
Cooking loss (%)	355	31.1	3.37	10.8	17.9 - 37.6
Drip loss (%)	372	1.31	0.45	34.4	0.1 - 3.0
Colour L*	453	35.9	2.64	7.35	29.1 - 45.3
Colour a*	453	13.2	1.57	11.9	9.00 - 17.9
Colour b*	455	10.6	1.45	13.7	6.00 - 15.3
Shear-force (N)	238	49.8	16.6	33.3	20.2 - 97.0

N: number of records; SD: standard deviation; CV: coefficient of variation

6.3.2 Environmental effects denoted by predicted fixed effect means and regressions

All traits were influenced by birth year (P <0.001). Year effects were not tabulated though as birth years are transient and not repeatable. Birth year effects depend on a combination of unique climatic and managerial effects that could vary and affect the available grazing. The birth year by sex interaction was present in most traits such as slaughter weight, dressing percentage, pH and temperature after 48 hours, fat depth at the 13th rib and the rump, cooking loss and surface colour (L*, a* and b*) (P <0.001). This interaction is explained by the rams and ewes being maintained in the same flocks but separated on sex prior to slaughter. It is difficult to ensure that grazing conditions are similar for ewe and ram flocks (Brash *et al.*, 1994a; 1994b; Cloete *et al.*, 2007b), which contributes to this interaction being commonly observed (Cloete *et al.*, 1998). Dam age did not influence any of the traits (P >0.05), but the effects of breed, sex and birth type are presented in Tables 6.2 to 6.4.

Slaughter weight, carcass weight and dressing percentage increased on average respectively with 0.077 kg, 0.063 kg and 0.057% per day of age. Cloete et al. (2007a) reported that slaughter weight increased by 0.17 kg/day of age in lambs slaughtered at a much younger age. The ultimate pH at 48 hours post slaughter increased on average with 0.0029 units per day of age. Drip loss increased on average with 0.0094% per day of age. The lightness of the meat increased by 0.051 lightness units for each day that animal age increased.

6.3.2.1 Effect of breed

The effect of breed on slaughter weight approached significance with Dormers tending to be 3.7% heavier than their SAMM contemporaries (*P* =0.052; Table 6.2). Van der Merwe *et al*. (2020) found slaughter weights of 44.2 kg for SAMMs and 42.7 kg for Dormers at respectively 114 ± 4.8 and 110 ± 3.6 days of age not to be significantly different. Cloete *et al.* (2004a; 2012) did not report significant differences between these breeds in slaughter weight at 18 months of age (55.2 ± 0.7 kg for Dormers vs 54.2 ± 0.9 kg for SAMMs) or at 20 months of age (61.4 ± 1.4 kg for Dormers vs 63.2 ± 1.3 kg for SAMMs). Carcass weight similarly did not differ between the two breeds (*P* =0.25; Table 6.2). Carcass weights were similarly independent of breed in previous studies (Cloete *et al.,* 2012; Van der Merwe *et al*., 2020). However, the carcass weights in the study by Cloete *et al*. (2004a) differed in favour of Dormers (23.2 ± 0.4 vs 21.7 ± 0.2 kg at 18 months of age; *P* <0.05).

Table 6.2 Predicted means (± SE) depicting the effect of breed (South African Mutton merino - SAMM or Dormer) on carcass and meat quality traits at 324 ± 52 days of age collected from 2016 to 2019.

Trait	Breed		Significance
	SAMM	Dormer	
Carcass traits			
Slaughter weight (kg)	49.0 ± 0.65	50.9 ± 0.46	0.05
Carcass weight (kg)	20.7 ± 0.38	21.2 ± 0.27	0.25
Dressing percentage (%)	42.2 ± 0.31	42.4 ± 0.20	0.63
Meat quality traits			
pH 45 min	6.75 ± 0.04	6.80 ± 0.03	0.28
pH 48 hr	5.66 ± 0.02	5.70 ± 0.01	0.14
Temp 45 min (°C)	30.2 ± 0.33	30.5 ± 0.21	0.51
Temp 48 hr (°C)	5.22 ± 0.10	4.91 ± 0.07	*
Fat 13th rib (mm)	2.14 ± 0.07	2.33 ± 0.07	0.14
Fat rump (mm)	4.18 ± 0.15	5.00 ± 0.15	*
Cooking loss (%)	31.4 ± 0.18	30.4 ± 0.18	**
Drip loss (%)	1.36 ± 0.04	1.38 ± 0.03	0.58
Colour L*	36.7 ± 0.27	35.0 ± 0.16	**
Colour a*	13.0 ± 0.14	13.3 ± 0.09	*
Colour b*	10.7 ± 0.10	10.6 ± 0.08	0.40
Shear-force (N)	45.7 ± 0.99	44.3 ± 0.99	0.55

* *P* <0.05; ** *P* <0.01; actual significance for *P* >0.05

Breed did not affect dressing percentage (*P* =0.63; Table 6.2). The overall dressing percentages reported by Van der Merwe *et al*. (2020) were slightly higher than those in the current study but were also independent of breed at 49.8% for SAMMs and 48.0% for Dormers. Dressing percentages reported by Cloete *et al.* (2012) also did not differ between SAMMs and

Dormers and the recorded dressing percentages corresponded well with the current study at 43.7 and 44.4%, respectively. Cloete *et al*. (2004a) reported a significant difference between the two breeds for dressing percentage, amounting to respectively 41.5 and 44.2%. Brand *et al*. (2018) indicated that dressing percentage was directly correlated with the level of subcutaneous fatness. Lambs with a greater subcutaneous fat distribution had a higher dressing percentage. Similarly, dressing percentage was also affected by age (Brand *et al*., 2017). It should, however, be considered that Dormer lambs in the study by Cloete *et al*. (2004a) had four months of wool growth while the SAMMs were recently shorn. This difference could have contributed to the observed breed difference previously reported.

Values for pH recorded at 45 min and 48 hours post slaughter was not significantly influenced by breed. The temperatures of the carcasses measured 45 min post slaughter did not differ significantly between breeds, but the temperature measured 48 hours post slaughter was on average 0.31 °C higher in SAMM yearlings than in Dormers (P <0.05). Van der Merwe *et al*. (2020) accordingly reported pH and temperature values, measured at 30 min and 24 hours post slaughter, which corresponded well with the means in this study with a pH and temperature range of 6.68 to 6.88 and 34.8 to 35.3 °C at 30 min post slaughter and with pH and temperature range of 5.52 to 5.54 and 4.6 to 4.7 at 24 hours post slaughter. Similarly, no breed differences were observed. Values for pH recorded 45 min and 48 hours post slaughter in the study of Cloete *et al*. (2012) corresponded well with those in the current study, also without a significant breed effect (6.86 ± 0.06 and 5.54 ± 0.69 for SAMMs vs 6.80 ± 0.06 and 5.67 ± 0.76 for Dormers. The pH after 48 hours recorded by Hoffman *et al*. (2003) also did not differ between breed types and ranged from 5.56 for Dormer and SAMM crosses to 5.71 for Dormer and Merino crosses. Devine *et al*. (1993) contended that an ultimate pH between 5.8 and 6.0 was undesirable. The tenderness and texture of meat deteriorated at an ultimate pH of 5.8 to 6.0 while an ultimate pH above 5.8 affected the flavour, juiciness and aroma of the meat. The ultimate pH of both breeds was lower than this range, at 5.67 and 5.70 for SAMMs and Dormers respectively and should thus be fine. Previous studies recorded ultimate pH values outside of this range. According to Naudé *et al*. (2018), ultimate pH was heritable at 0.47 in South African sheep allowing opportunities for selective breeding.

Fat depth at the rump differed significantly between breeds with Dormers being 0.82 mm fatter than their SAMM contemporaries, although no breed difference was found at the 13th rib (P =0.14; Table 6.2). Similar to findings in the present study, Van der Merwe *et al*. (2020) also reported no breed difference in fat depth measured at the 13th rib (3.37 ± 0.233 vs 3.24 ± 0.307 mm for Dormers and SAMMs respectively) at 110 ± 3.6 days of age for Dormers and 114 ± 4.8 days of age for SAMMs. Both breeds are considered as medium maturing and presumably deposit fat at an equal rate (Van der Merwe *et al*., 2019; 2020). Cloete *et al*. (2004a) earlier

argued that Dormers could have deeper fat cover due to being an early maturing breed but based on later studies this perception has changed. This implies that they were physiologically more developed than SAMMs at the same stage. This contention was not supported by later studies. Fat depth at the rump at 20 months of age (3.20 ± 0.34 vs 2.51 ± 0.0.33 mm for Dormers and SAMMs, respectively) was independent of breed in a previous study on Dormer and SAMM sheep and the fat depth measured at the 13th rib (2.71 ± 0.37 vs 2.04 ± 0.36 mm for Dormers and SAMMs respectively) was not as thick as that measured at the rump (Cloete *et al*., 2012). In contrast, Cloete *et al*. (2004a) also reported that Dormers were fatter *(P* <0.05) than SAMM contemporaries at 18 months (1.62 ± 0.09 vs 1.20 ± 0.11 mm for Dormers and SAMMs respectively). The present analyses used a substantially larger data set than any of the previous studies of pasture-fed sheep of the same breeds, while the animals in other studies were slaughtered at a younger age. Age and maturity type possibly combined to give the results that were obtained. Carcasses with subcutaneous fat depth of 1 - 4 mm fat measured between the 3rd and 4th lumbar vertebrae and 25 mm from the midline at the 13th rib are considered as the optimum fat level in South Africa (Government Notice No. R. 863, 2006).

The mean cooking loss of SAMM meat was one percentage unit higher than that of Dormer meat (*P* < 0.01), whereas drip loss was independent of breed (*P* =0.58; Table 6.2). Cooking loss did not differ between breeds in the study of Van der Merwe *et al*. (2020), but the values was higher than in the current study, with a value of 38.6% for SAMMs and 40.2% for Dormers. The muscle pH did not differ between SAMM and Dormer yearlings, therefore drip loss also did not differ (Table 6.2; Van der Merwe *et al*., 2020). Drip loss values reported by Van der Merwe *et al*. (2020) amounted to 1.1% for SAMM lambs and 1.3% for Dormers. Hoffman *et al*. (2003) and Cloete *et al*. (2004a; 2012) found that cooking loss and drip loss did not differ significantly between breeds. The present study involved younger sheep and a larger sample size compared to the latter studies, both of which could be causative to the results obtained. From Table 6.2 it is evident that drip loss might be inversely correlated to cooking loss. Thomas *et al*. (2004) argued that a low drip loss (%) results in more water being available to be lost during cooking and a higher percentage cooking loss is expected. As a result of the greater cooking loss in SAMM meat samples, higher shear-force values were also observed (Table 6.2). This could be due to the density of muscle fibres increasing within the cooked meat samples as a result of losing moisture (Van der Merwe *et al*., 2020).

South African Mutton Merinos had slightly lighter (4.6%) and less vividly red (2.3%) meat compared to Dormers. The b* value was not significantly influenced by breed (*P* =0.40). When considering the meat quality parameters for meat colour (L*, a* and b*), even the significant differences were so small that one would not visually perceive a difference between the meat of the two breeds. The colour values of Van der Merwe *et al*. (2020) showed no breed difference

but corresponded well with the current study amounting to 38.85 for lightness, 12.59 for redness and 10.95 for yellowness in SAMMs and respectively 38.54, 12.64 and 10.46 for Dormers. Cloete *et al*. (2012) also reported no breed differences for the colour traits. The means in the latter study suggested that the meat in the latter study might have been slightly darker compared to the current study (34.2 for SAMMs *vs*. 32.8 for Dormers). Although Dormer meat may be slightly darker and more vividly red than SAMM meat in the current study, the values differed by such a small margin that a consumer might not be able to visually perceive the differences and is likely to still regard the meat as acceptable. According to Khliji *et al*. (2010) the average consumer accept lamb meat with an L* value (lightness) of 34 and an a* value (redness) of 9.5 as a lower limit, while the majority of the consumers still accept lamb meat with an L* value of up to 44 and an a* value of up to 14.4. The colour values of both breeds in the current study are within this range (Table 6.2). Hedrick (1983) reported that muscles with a high intramuscular fat content have higher muscular brightness values as fats have high light reflection properties.

Shear-force was not significantly affected by breed (P =0.55; Table 6.2). Shear-force values reported by Van der Merwe *et al*. (2020) agreed with those in the current study and also did not differ significantly between SAMMs (40.34 N) and Dormers (46.56 N). Cloete *et al*. (2012) did not find differences between breeds for shear-force, but the meat was tougher than that of the current study at 111.5 N for SAMMs and 116.2 N for Dormers. It should be considered that animals in the latter study were older at slaughter. Hoffman *et al*. (2003) concluded that the shear-force of meat from Dormer-sired crossbred lambs was greater than that of other crossbreeds, including with SAMMs as a dam breed, suggesting a possible breed effect. According to Destefanis *et al*. (2008) the Warner-Bratzler shear-force values obtained from the current study would not be described as tough meat, but rather fall in an intermediate category.

6.3.2.2 Effect of sex

Rams were 11.3% heavier at slaughter than ewes (P <0.001; Table 6.3). Cloete *et al.* (2004a; 2012) and Van der Merwe *et al.* (2020) similarly reported that rams were respectively 31.3, 16.7 and 10.1% heavier than ewes at slaughter. Ram yearlings recorded 8.7% heavier carcass weights compared to their ewe contemporaries (P <0.001; Table 6.3). Cloete *et al.* (2004a; 2012) and Van der Merwe *et al.* (2020) also observed carcass weights of rams to be heavier relative to ewes at respectively 30.8, 5.9 and 6.6%. The higher slaughter and carcass weight of rams could be due to the commonly reported sex-linked dimorphism for growth and mature size (Kirton *et al.*, 1995). Ewes had 3.9% higher dressing percentages than rams (P <0.001; Table 6.3). Dressing percentages of ewes and rams did not differ in the study of Cloete

et al. (2004a; 2007), but Van der Merwe *et al.* (2020) and Cloete *et al.* (2007a) reported that ewes had a respectively 3.9 and 9.8% higher dressing percentage than rams. The testes are removed from ram carcasses and contribute to the offal component, which reduces their dressing percentages. A greater subcutaneous fat cover also increases dressing percentage. Ewes, with a greater distribution of subcutaneous fat, will thus be advantaged (Kirton *et al.*, 1995; Cloete, 2002; Brand *et al.,* 2018; Van der Merwe *et al.,* 2020), which seemed to be the case in this study as well.

Sex did not influence pH 45 min post slaughter, but the pH of rams after 48 hours in the cooler was 2.8% higher than that of ewes (P <0.001; Table 6.3). These results agreed with those of Cloete *et al.* (2012) where pH at 45 min did not differ significantly between sexes, but rams had 7.6% higher pH 48 hours post slaughter than ewes. Van der Merwe *et al.* (2020) and Teixeira *et al*. (2005) found no significant differences between sexes in pH post slaughter. McGeehin *et al*. (2001) also reported no difference between rams and ewes 45 min post slaughter, but the pH decline of females occurred at a faster rate than rams. It was speculated that this could be due to the difference in fat cover. It is assumed that the difference in ultimate pH may also result in a drip loss difference between sexes (Van der Merwe *et al.,* 2020).

Table 6.3 Predicted means (± SE) depicting the effect of sex (male or female) on carcass and meat quality traits of South African Mutton Merino (SAMM) and Dormer yearlings at 324 ± 52 days of age, measured from 2016 to 2019.

Trait	Sex		Significance
	Male	Female	
Carcass traits			
Slaughter weight (kg)	53.0 ± 0.43	47.0 ± 0.60	***
Carcass weight (kg)	21.9 ± 0.25	20.0 ± 0.38	***
Dressing percentage (%)	41.4 ± 0.22	43.1 ± 0.32	***
Meat quality traits			
pH 45 min	6.76 ± 0.03	6.79 ± 0.04	0.48
pH 48 hr	5.76 ± 0.01	5.60 ± 0.02	***
Temp 45 min (°C)	28.7 ± 0.21	32.0 ± 0.29	***
Temp 48 hr (°C)	5.10 ± 0.07	5.02 ± 0.09	0.20
Fat 13th rib (mm)	1.42 ± 0.07	3.06 ± 0.11	***
Fat rump (mm)	2.95 ± 0.16	6.22 ± 0.22	***
Cooking loss (%)	31.9 ± 0.18	30.0 ± 0.29	*
Drip loss (%)	1.22 ± 0.025	1.51 ± 0.041	***
Colour L*	36.4 ± 0.15	35.3 ± 0.26	***
Colour a*	13.3 ± 0.088	13.0 ± 0.12	0.05
Colour b*	10.7 ± 0.075	10.6 ± 0.10	0.95
Shear-force (N)	48.9 ± 0.99	41.1 ± 0.99	***

* P <0.05; ** P <0.01; *** P <0.001; actual significance for P >0.05

The carcass temperatures of ewes 45 min post slaughter were 3.3 °C higher than in rams (P <0.001) while carcass temperature 48 hours post slaughter was independent of sex (Table

6.3). Van der Merwe *et al.* (2020) did not report sex differences in temperatures post slaughter. The higher initial temperature of ewe carcasses could be due the higher subcutaneous fat cover of ewes, the effect wearing off by 48 hours post slaughter when no sex difference was observed.

The subcutaneous fat cover of ewes was 54% greater at the 13th rib and 53% greater at the rump site (P <0.001; Table 6.3). Cloete *et al.* (2004a) and Van der Merwe *et al.* (2020) found no significant sex-related differences in fat depth. Cloete *et al*. (2007a or b; 2012) reported that ewes had a thicker fat cover at the 13th rib and rump than rams (P <0.05). The current study confirmed that greater fat depths were observed nearer to the rump while fat depth at the 13th rib was thinner (Van der Merwe *et al.,* 2020). It is generally accepted that ewes reach maturity earlier than rams and are overall fatter with more subcutaneous fat when slaughtered (Butterfield, 1988; Kirton *et al*., 1995; Dimsoski *et al.,* 1999).

The meat of rams had a 1.9% higher cooking loss than that of their ewe contemporaries (P <0.05; Table 6.3). Males had respectively a 3.0% and 10.3% higher cooking loss than ewes (P <0.05) in the studies by Cloete *et al*. (2012) and Van der Merwe *et al.* (2020). Ewes recorded a 0.29% higher drip loss than rams (P <0.001; Table 6.3). Van der Merwe *et al.* (2020) and Cloete *et al*. (2012), in contrast, recorded no significant sex differences in drip loss. Cooking loss is directly correlated with shear-force and negatively correlated with drip loss. A greater cooking loss is related to the density of muscle fibres increasing within the cooked meat sample since moisture is lost with a resultant reduced drip loss value (Thomas *et al.,* 2004; Van der Merwe *et al.,* 2020). Lower cooking loss is also associated with a thicker fat cover (Safari *et al*., 2001)

Rams had a slightly lighter meat colour (3.0%) when compared to ewes (P <0.01; Table 6.3). The redness and yellowness values were not dependent on sex (P >0.05). These results agreed with those of Teixeira *et al*. (2005) and Van der Merwe *et al.* (2020). The latter authors reported respectively a 3.1 and 3.6% difference in the lightness of meat between rams and ewes. They also found no significant sex-related differences in redness and yellowness values. Cloete *et al*. (2012) reported that the meat of rams was lighter (3.5%) and less vividly red (8.1%) than that of ewes (P <0.05). However, they also observed no significant difference in yellowness values. Khliji *et al.* (2010) reported that, on average, Australian consumers accepted lamb meat with a lightness value of 34 and a redness value of 9.5. The colour trait values for meat in this study were thus higher than the average accepted threshold values, rendering the meat acceptable for consumers.

The shear-force of ram meat was 16% higher than that of ewes (P <0.001; Table 6.3). Ram meat can be included in the intermediate tenderness category while the average shear-

force of ewes can be regarded as tender (Destefanis *et al.,* 2008). Cloete *et al*. (2012) also observed an 8.4% higher shear-force in rams than in ewes. In contrast, Teixeira *et al*. (2005) and Van der Merwe *et al.* (2020) found no sex difference for shear-force. There is other evidence in the literature that ewe meat is more tender than ram meat (Hopkins *et al.,* 2007; Okeudo & Moss, 2008). Safari *et al*. (2001) found a significant correlation between shear-force and taste-panel tenderness.

6.3.2.3 Effect of birth type

Singles were 10.4% heavier at slaughter with 12.9% heavier carcass weights than multiples (P <0.001; Table 6.4). Singles also had a 1.87% higher dressing percentage than multiples (P <0.01). These results accorded with those of Cloete *et al*. (2007a) who reported that singles had 5.5% higher dressing percentages than multiples (P <0.05). Multiples had slightly lighter and less vividly red meat compared to singles (P <0.01), but the yellowness value was not significantly influenced by birth type.

Table 6.4 Predicted means (± SE) depicting the effect of birth type (singles or multiples) on carcass and meat quality traits of South African Mutton Merino (SAMM) and Dormer yearlings at 324 ± 52 days of age, measured from 2016 to 2019.

Trait	Birth type		Significance
	Singles	Multiples	
Carcass traits			
Slaughter weight (kg)	52.7 ± 0.60	47.2 ± 0.47	***
Carcass weight (kg)	22.4 ± 0.35	19.5 ± 0.28	***
Dressing percentage (%)	42.7 ± 0.20	41.9 ± 0.20	**
Meat quality traits			
pH 45 min	6.81 ± 0.04	6.74 ± 0.03	0.12
pH 48 hr	5.68 ± 0.02	5.69 ± 0.01	0.67
Temp 45 min (°C)	30.5 ± 0.28	30.2 ± 0.22	0.40
Temp 48 hr (°C)	5.05 ± 0.09	5.07 ± 0.07	0.84
Fat 13th rib (mm)	2.27 ± 0.07	2.20 ± 0.07	0.51
Fat rump (mm)	4.78 ± 0.15	4.40 ± 0.15	0.076
Cooking loss (%)	30.9 ± 0.18	31.0 ± 0.18	0.76
Drip loss (%)	1.34 ± 0.036	1.40 ± 0.028	0.18
Colour L*	35.5 ± 0.22	36.2 ± 0.18	**
Colour a*	13.4 ± 0.12	12.9 ± 0.092	***
Colour b*	10.7 ± 0.10	10.6 ± 0.078	0.31
Shear-force (N)	45.1 ± 0.99	44.9 ± 0.99	0.90

* P <0.05; ** P <0.01; *** P <0.001; actual significance for P >0.05

Birth type did not significantly influence cooking loss, drip loss, shear-force, pH or temperature post slaughter (Table 6.4). Fat depth at the 13th rib was not significantly affected by birth type, while there was a tendency for multiples to have a thinner rump fat depth than singles (P =0.08). These results were in contrast with those of Greeff *et al.* (2003) and Cloete *et*

al. (2007a). Cloete *et al*. (2007a) observed that singles had a 16% thicker fat depth at the 13th rib and a 15% thicker fat depth at the rump site than multiples (P <0.05). This is possibly a reflection of their improved maternal care during their early life.

6.4 Conclusion

The observed breed differences were small and show that SAMMs and Dormers performed very similarly in terms of slaughter weight as well as carcass and meat quality traits while grazing pastures. Dormers tended to have a slightly higher slaughter weight compared to SAMMs, but no difference in dressing percentage between the two breeds was observed at 324 days of age. The thicker rump fat depth of Dormers compared to their SAMM contemporaries probably indicate that Dormers were selected for a better fat score at an earlier age, in line with their designation as a terminal sire breed. Breed differences in drip loss and colour traits were probably too small for consumers to perceive a difference.

Currently there is no recording of meat quality traits the in National Small Stock Improvement Scheme. Viewed against the background of international sheep recording, this state of affairs is undesirable and requires effort to align sheep recording in South Africa with international benchmarks. Lastly, both breeds performed well for meat production. Other meat characteristics together with growth, wool and reproduction traits should also be investigated to compare the two breeds for total economic yield. Meat quality as selection trait for sheep in South Africa should be promoted to ensure progress in this field to be able to achieve the desired meat quality demanded by consumers.

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Chapter 7
General conclusions and recommendations

This thesis was undertaken to estimate environmental and genetic parameters and predict trends for lamb survival, growth and wool traits of the Elsenburg Dormer and SA Mutton Merino (SAMM) resource flocks. Both flocks are recognized South African resource flocks and have data available that were collected since 1943 for Dormers and since 1955 for SAMMs. The thesis involved results pertaining to the impact of environmental and genetic parameters and trends (Chapter 2 and 3), response to selection in Dormers (Chapter 4), a comparison of these two breeds for growth and wool traits (Chapter 5), as well as slaughter and meat quality traits (Chapter 6). These topics will be addressed subsequently.

7.1 Environmental parameters

Results presented in Chapters 2 and 3 confirmed results from literature that showed that the performance of Dormers and SAMMs are affected by environmental effects such as birth year, sex, dam age and birth type, as well as regressions on age at recording. An interaction between birth year and sex was also common, particularly in post weaning traits when the animals were grazed in flocks that were separated on sex. The study also provided plausible estimates for environmental effects on wool traits of Dormer and SAMM sheep. To the knowledge of the author, this is the first time that comprehensive environmental parameters were published for an important coarse-woolled South African sheep breed. Similarly, although officially a dual-purpose breed, wool traits are not considered during the national evaluation of the SAMM breed (Schoeman *et al*., 2010). This study therefore contributes to the limited information on the nature of environmental influences on wool traits in this breed.

It is important to consider these environmental effects during the genetic evaluation of sheep, to ensure that breeding values are not biased due to environmental variance not accounted for. It is therefore recommended that fixed effect models applied within the mixed models used for genetic evaluation should be chosen with great care, to ensure that all effects with the potential to explain variation associated with systemic effects are included. Failure to do so will result in inaccurate breeding values and is likely to compromise realized genetic gains.

7.2 Genetic parameters

The magnitude of the data on early growth traits in Chapters 2 and 3 were such that it was possible to model litter effects in early growth traits separately from dam permanent

environmental effects. The heritability estimates for growth traits and lamb survival ranged from low to moderate but the wool traits that were measured were all highly heritable. Estimates for all of the traits corresponded with multi-trait heritability estimates as well as with estimates reported in the literature. Although just below or within ranges in the literature, genetic variance ratios for weaning weight in SAMMs were lower than anticipated. No evident explanation was found for this result and it would be important to find out if this is a characteristic of SAMMs in general or if it is limited to the Elsenburg flock. Results reported by Neser *et al*. (2000) suggested genetic parameters for weaning weight that were more closely aligned with literature values, so it might be unique to the Elsenburg flock. The direct genetic, phenotypic and environmental correlations from the three-trait analyses involving live weight traits ranged from moderate for correlations involving birth weight to high when weaning weight was correlated to yearling weight. It was also observed in SAMMs that the dam PE correlations of birth weight with weaning weight and yearling weight were high and the correlation of weaning weight with yearling weight had an extremely high value that did not differ from unity. The correlations amongst yearling weight and the wool traits ranged from low to moderate and not all were significant.

Only early growth and conformation traits are considered during the national evaluation of these breeds and no emphasis is placed on wool traits (Schoeman *et al*., 2010). This study supplements the limited information on genetic parameters for wool traits in these breeds. This study also showed that weight traits are low to moderately heritable and that higher birth weights might lead to higher lamb survival rates. This, however, is only applicable to a point, since phenotypic results clearly indicated that heavier lambs are at risk owing to higher levels of dystocia (Hickson *et al*., 2006). Since wool traits of both breeds were highly heritable, it ought to be feasible to include it in selection indexes for maximized economic gain, specifically in SAMMs. Correlations with other traits will be important in determining the emphasis that needs to be placed on such traits. It is also important to include the wool traits of SAMMs in the national evaluation of the dual-purpose breed. Moreover, it is recommended that studies on genetic parameters are extended to traits associated with disease resistance and reproduction that were not considered in this study. The only study involving aspects of disease resistance that could be sourced was that of Cloete *et al*. (2016), who reported genetic parameters for faecal worm egg count as well as other traits associated with the FAMACHA© system.

7.3 Genetic trends

Chapter 2 and 3 included the evaluation of the genetic change in the growth and wool traits of the SAMM and Dormer resource flocks. Selection in both these breeds was previously

based on improved early growth and conformation. It was observed that no direct selection pressure had been placed on any of the wool traits in either breed as these genetic changes were small. The genetic change in all the traits was disappointingly slow for both breeds, and even more so in SAMMs, compared to the expected 1% achievable gain from genetic selection. The genetic change in yearling weight in Dormers was the fastest gain of all traits, amounting to 0.45% p.a. of the overall phenotypic mean. Genetic correlations with yearling weight in SAMMs were included in the analyses used for the estimation of genetic trends of the early weight traits and also when the genetic trends for the yearling traits were calculated over a shorter time span. The estimated genetic change from both approaches was quite similar at respectively 0.09% and 0.08% p.a. It is recommended that the impact of selection for subjective conformation traits should be studied further as the realized gains were evidently smaller than those attainable in theory.

7.4 Response to selection in Dormers

Selection responses in the Dormer breed was further investigated in Chapter 4 to evaluate the direct and correlated responses to selection for direct and maternal breeding values for weaning weight, separately and in tandem over a shorter period since 2013. It was evident that little response was obtained from direct selection on maternal breeding values for weaning weight. This generalization applied to both the Weaning Weight Maternal line as well as the line selected for above average breeding values both for Weaning Weight Direct and Weaning Weight Maternal. In contrast, selection for direct breeding values resulted in substantial genetic gains in the Weaning Weight Direct line, amounting to 0.79% of the overall phenotypic mean. It was noted that the correlated genetic gain in yearling weight for the Weaning Weight Direct line was positive amounting to 1.01% per annum. This result could be ascribed to the generally higher heritability of yearling weight compared to weaning weight, as well as the near unity genetic correlation between the two traits as reported in Chapter 3. Positive direct genetic change for yearling weight was also noticeable for the Weaning Weight Both selection line as well as the Weaning Weight Maternal selection line.

These data were obtained over a short period and selection should be continued to study other correlated responses. Since the lines are relatively small, it could be argued that the Weaning Weight Both line should be phased out to allow more animals for each of the remaining lines, namely the Weaning Weight Direct and Weaning Weight Maternal lines. It is important that the study should continue to get an indication of correlated responses in ewe reproduction.

7.5 The comparison of Dormer and SAMM sheep

7.5.1 Live weight and wool traits

Chapter 5 confirms the influences of environmental effects and regressions on age at recording on live weight and wool traits and will not be elaborated upon. The comparison of the live weight and wool traits of Dormer and SAMM sheep in Chapter 5 indicated that breed influenced all of the traits except clean fleece weight. The dual-purpose SAMM lambs were heavier at birth than their Dormer contemporaries. Dormers were heavier than SAMMs at weaning, also with heavier yearling weights. Dormer lambs had better survival rates than SAMM lambs. Also, breed interacted with birth weight for lamb survival. The survival of Dormer lambs peaked at 5 kg birth weight, while their SAMM contemporaries peaked at 6 kg birth weight with a slightly lower survival rate in lambs exceeding these optimum birth weights. Overall, both breeds performed quite well in this analysis. It is recommended that reproduction of the two breeds should also be compared in the same environment, to allow a valid comparison over the full spectrum of economically important traits.

7.5.2 Slaughter and meat quality traits

Chapter 6 evaluated the effect of breed on slaughter traits and is also the only chapter that investigated the effect of environmental factors, such as birth year, sex, dam age and birth type on these traits. It was evident that SAMM and Dormer yearlings were, in general, quite similar in terms of slaughter and meat quality traits. This was also found in previous smaller studies involving the two breeds (Cloete *et al*., 2004).

It was suggested that Dormers could have a slightly heavier slaughter weight than SAMM yearlings, although carcass weight and dressing percentage was independent of breed. Dormers were slightly fatter at the rump than their SAMM contemporaries, but no breed difference was found at the 13th rib. Carcasses with subcutaneous fat depth of 1 to 4 mm fat that is measured at the rump and 13th rib are considered as the optimum fat level in South Africa. Given that the animals studied were raised on pasture, no carcasses were too fat in the present study. Breed differences in meat colour traits were so small that one would not visually perceive a difference between the meat of the two breeds. Meat from both breeds was still within the ranges for consumer acceptability.

Dam age did not influence any of the slaughter or meat quality traits. Birth type did not influence cooking loss, drip loss shear-force, pH and temperature post slaughter or fat depth at both sites but singles were heavier at slaughter, with heavier carcass weights and higher dressing percentages than multiples. The meat of multiples was slightly lighter and less vividly red compared to singles, while yellowness was also not affected by birth type. The birth year

and sex interaction were evident in most of the carcass and meat quality traits. Males had heavier slaughter and carcass weights than their female contemporaries, which could be ascribed to the difference in growth rate and mature size between sexes. However, the higher dressing percentage of females compared to males could be due to the removal of the testes from male carcasses that contributes to the offal component and decreases their dressing percentage, while females also had a greater subcutaneous fat cover. There were sex differences in carcass temperature, ultimate pH, drip loss and cooking loss, most of which were probably associated with the well-described sex difference in fat cover in the literature. Males had slightly lighter and redder meat compared to females. These colour traits were higher than the average threshold values, making the meat acceptable for consumers. The meat of male yearlings was also less tender than that of females. The meat from males could be included in the intermediate category whereas the meat of females could be regarded as tender.

The two breeds performed according to the roles they play in the South African sheep industry. However, it was clear that both breeds would excel when reared for meat production, although SAMM yearlings could obtain better prices for wool quality when their finer wool is marketed, since it would still qualify for apparel wool. Dormer wool, in contrast, is typically coarse and only of value in the carpet wool market. It is recommended that further research on meat traits should involve ultrasound measurements on fat depth and eye muscle depth. These records are important to calibrate scanned values against actual slaughter measurements and also to align the South African industry with international standard practice.

7.6 General considerations and recommendations

It is recommended that the disappointing genetic change in the SAMM flock should be addressed in consultation with the Breeders' Association. Based on industry needs, the selection practice in the Elsenburg SAMM flock could be amended to address constraints in the national flock.

The role that selection for subjective traits plays in the less-than-optimal genetic progress should be studied further. Since information on the reasons for culling animals is available in both flocks, it is recommended that this information be used to assess the impact of specific culling decisions. In this way, it is conceivable that selection could be placed on a sounder basis, as directed by economic principles. Less than optimal genetic gains in economically important traits have been reported in literature when subjective traits are emphasized (Olivier *et al*., 1995; Olivier, 2014).

Finally, it is contended that genetic resources under institutional control are important attributes to the national animal recording scheme. Both flocks participate in the national performance recording scheme and can play an important role in the testing of new traits not recorded under the auspices of ovine performance recording at present. It is also well known that genomic selection has the potential of markedly increasing the rate of genetic improvement of breeds, particularly in hard-to-measure traits that are not routinely recorded in all flocks (Cloete et al., 2014). Resource flocks such as those studied here, are of utmost importance to evaluate the genetic progress of the breeds, to address specific breed problems by conducting targeted research and to ultimately improve the targeted breeds for consumer needs.

Resource flocks such as the Elsenburg Dormer and SAMM flocks also have the potential to serve as part of a breed-specific genomic reference population for the prediction of genomic breeding values and ultimately genomic selection. Predicting accurate breeding values requires a well-linked reference population of individuals with a wide array of available genotypes and phenotypes. With industry sires that were commonly introduced to both flocks in the recent past, linkages to the industry flocks should not be a problem. In the Dormer breed, with a relatively small effective population size compared to the other commercial breeds (Sandenbergh, 2017), genomic selection should be an important consideration for the Dormer Breeders' Association. For this purpose, it is recommended that both flocks are maintained at Elsenburg and recorded for a wide array of phenotypes, especially for novel phenotypes not recorded in other industry flocks.

7.7 References

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